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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CLIMATIC MAPS OF GEOLOGIC INTEREST

BY STEPHEN S. VISHER

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ABSTRACT

Thirty maps of the United States showing climatic conditions which distinctly influence geologic processes are presented. They are based on official Weather Bureau data, and on a more extensive body of such data than has been available until recently. Several are original. They all show considerable regional contrasts which clearly or presumably correlate with various geologic processes and their consequences. Some of these correlations are pointed out.

INTRODUCTION

That some climatic conditions are of profound significance in geomorphology has long been realized. During recent years, with the accumulation of more adequate climatic data and with the completion of some rather detailed comparative studies, it is becoming evident that various climatic conditions commonly ignored are of considerable geomorphologic significance (Visher, 1937; 1941a; 1942a; 1944b). Hence, adequately presented data as to climatic contrasts afford a worth-while contribution to geologic literature.

The accompanying 30 climatic maps of the United States are based on recently available U. S. Weather Bureau data or studies thereof. The significance of the regional contrasts made conspicuous by these maps varies, of course, with the geologic processes. Several of the climatic conditions affect the rapidity and depth of mechanical weathering, others affect leaching, ground-water recharge, runoff erosion, wind erosion, wave action, shore-ice action, slumping, and the texture of the topography (stream spacing). Some of the climatic effects are direct, but many are indirect, operating through their effects upon the soil development and vegetative cover.

Here only a few of the geologic relations are mentioned; the chief contribution is to present effectively the regional contrasts in various climatic conditions which at least locally are of appreciable geologic importance.

PRECIPITATION CONDITIONS

GENERAL CONSIDERATIONS

The amount of precipitation and its time of fall profoundly influence runoff, groundwater accummulation, and the character of the regolith and vegetation. The map of the amount of annual average precipitation can now be supplemented by quite a number of additional maps of considerable geologic interest. For example, Figure 1, a map of the average precipitation in a wet year (only one-eighth of the years receive more), is relatively unfamiliar. It is a shaded completed copy of an official map of the average precipitation of the 10 wettest years of 40 (Kincer, 1941). In a

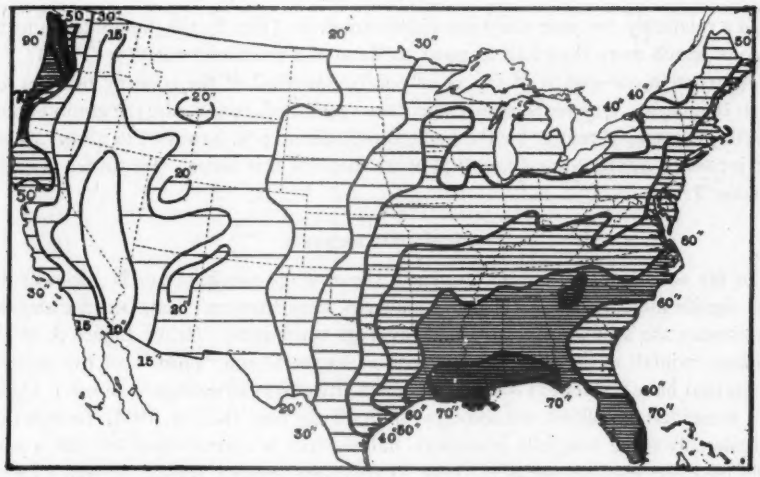

FIGURE 1.—*Precipitation totals in a relatively wet year*
Only one-eighth receive more; in inches

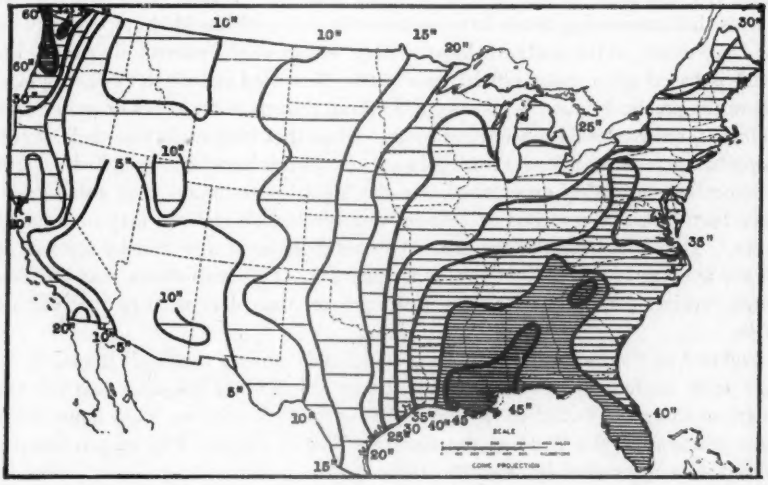

FIGURE 2.—*Precipitation totals in a relatively dry year*
Only one-eighth receive less; in inches

wet year little even of the West receives less than 10 inches (the commonly used limit of arid), while three southeastern areas and a northwestern area receive more than 70 inches, or considerably more than twice the weighted average annual precipitation in the United States, which is 29 inches. More than 100 inches are received in such a wet year in a small part of the southern Appalachians, and more than 125 inches in extreme western Washington.

In a relatively dry year (only one-eighth are drier) (Fig. 2), the precipitation totals are not much more than half as great as those of a relatively wet year (Fig. 1). It shows that in one-eighth of the years nearly one-third of the country receives less than 10 inches. Dry years greatly affect the vegetation, runoff, and the ground-water level. The special reason for the inclusion of this map is, however, to afford a basis for increased appreciation of several other maps of this series. Its source is as for Figure 1.

TORRENTIAL RAINFALL

So far as runoff erosion is concerned, the average precipitation is generally far less significant than the exceptional amounts sometimes received, because streams and slopes are adjusted to normal or average conditions. Hence Figure 3, of the greatest rainfall received during 1 month in 40 years, and Figure 4, of the greatest totals that have fallen in 24 consecutive hours, are of special geologic interest. Figure 3, a somewhat simplified, shaded copy of an official map (Kincer, 1941), reveals that occasionally more rain falls in a single month than is normal there for half a year. The greatest monthly totals in these 40 years are greater, indeed, in much of the country than are the annual totals there in the driest entire year of record. (For some details *see* Visher 1943a. Figure 3 shows the averages of several near-by stations, not the greatest recorded at a single station.) Figure 4, an original one, reveals that astonishing totals have occasionally fallen within 24 hours, especially in the Deep South, in the southern Appalachians, and in southwestern California. Figure 4 is based upon many official data partly presented elsewhere (Visher, 1941d) where the precise location is given of 293 official records of 10 inches or more (up to 23 inches) received in 24 consecutive hours. Since that 1941 study was made, several scores of scattered additional records of such heavy rains have been compiled. Figure 4 indicates reasonable expectancy, on the logical assumption that totals which have been officially recorded at near-by weather bureau stations may occasionally occur. Thus it is based on the greatest totals received at any near-by station, not on the average of several stations, as is Figure 3. This map shows that the Deep South receives totals three or more times greater than does most of the North or West.

Figure 5, of the frequency of totals of 6 inches or more of rain in 24 hours, reveals that daily rainfalls of this amount are at least 20 times as frequent near the Gulf Coast as along the Canadian border, and that totals of 6 inches in 24 hours are almost unknown in the West, except along the Pacific Coast. This map is based on official data assembled by Yarnell (1935).

Figure 6, a map of the percentage of the yearly precipitation which falls in days in which 2.5 inches or more is received, is a shaded simplified copy of one by Dyck and Mattice (1941). Near the Gulf of Mexico a large share, 20 to 35 per cent, of the annual precipitation total occurs on days of heavy rainfall, while in much of the North and most of the West less than 5 per cent falls on such days.

Figure 7 shows that rainfalls of 1 inch in 1 hour occur at least five times each average year in the Deep South but less than once in 3 years in the western third of the country and less than once a year in much of the North. This map is based on an official one by Dyck and Mattice (1941).

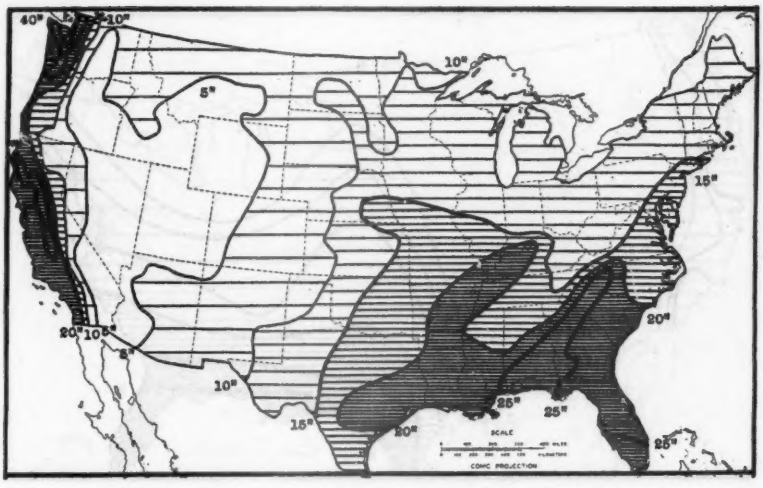

FIGURE 3.—*Greatest amount of rainfall received in 1 month in 40 years*
Local averages; in inches

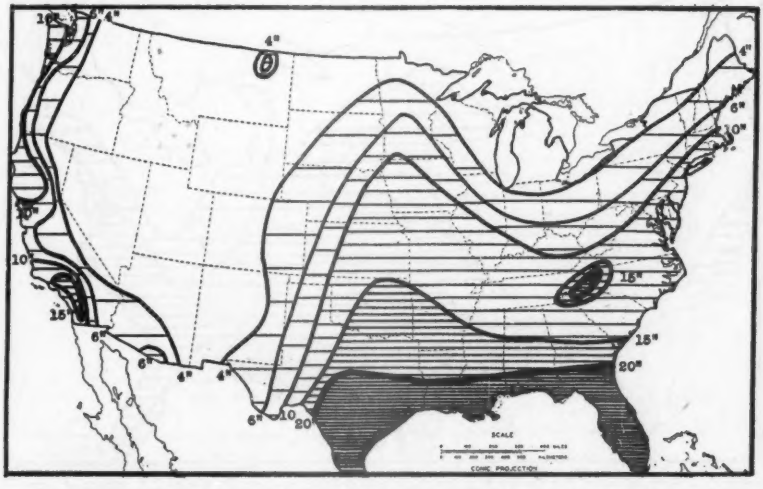

FIGURE 4.—*Greatest amount of rainfall in 24 consecutive hours in half a century*
Based on record downpours; in inches

Figure 8 indicates that downpours of 3 inches in 2 consecutive hours occur more than 20 times as often in the Deep South as near the Great Lakes or in the West. This map is based on data assembled by Yarnell (1935).

Figure 9, the frequency of very hard rains, affords a sort of summary of Figures 3–8 and many other maps. It is based on scores of maps by Yarnell and on more than a

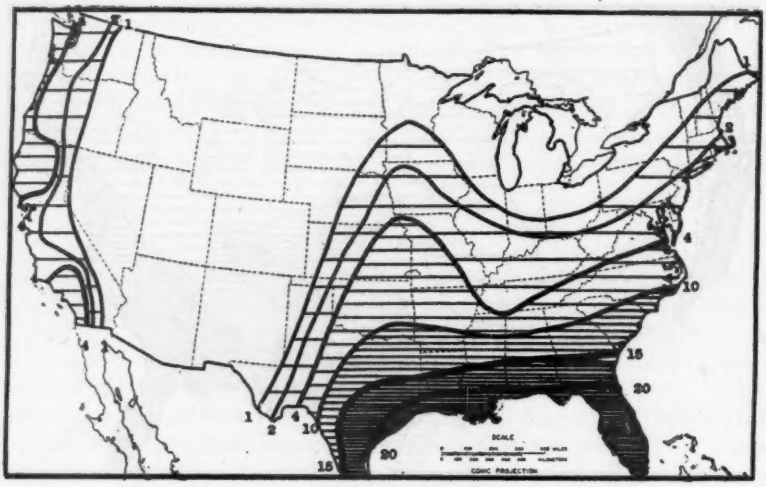

FIGURE 5.—*Frequency of daily totals of 6 inches or more of rain*
Times per century

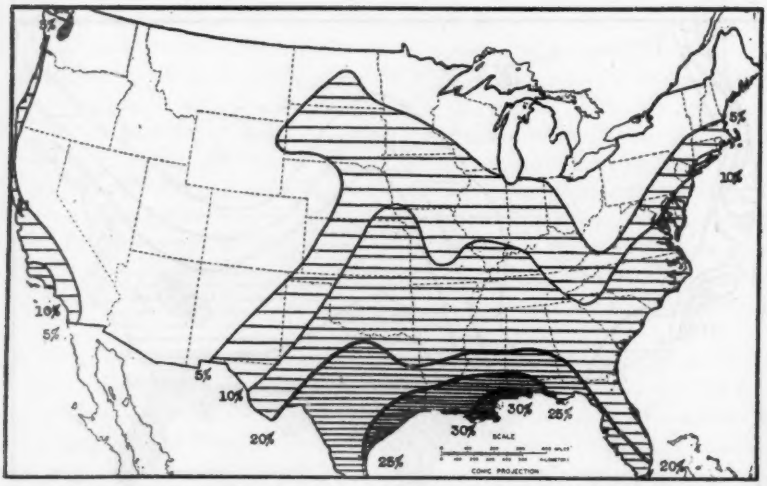

FIGURE 6.—*Percentage of the yearly precipitation which falls on days in which 2.5 inches or more falls*

dozen maps made by combining parts of his maps, to discover the frequency (times per decade or century) of rains of various magnitudes; also used were original maps of very heavy rainfalls published elsewhere (Visher, 1941c; 1941d). The definitions here used are as follows: Very hard rains are those which yield 2 inches of water within 30 minutes, 3 inches in an hour, 4 inches in 8 hours, 5 inches in 16 hours, or 6 inches or more in 24 hours; numerous means that there were five or more very hard

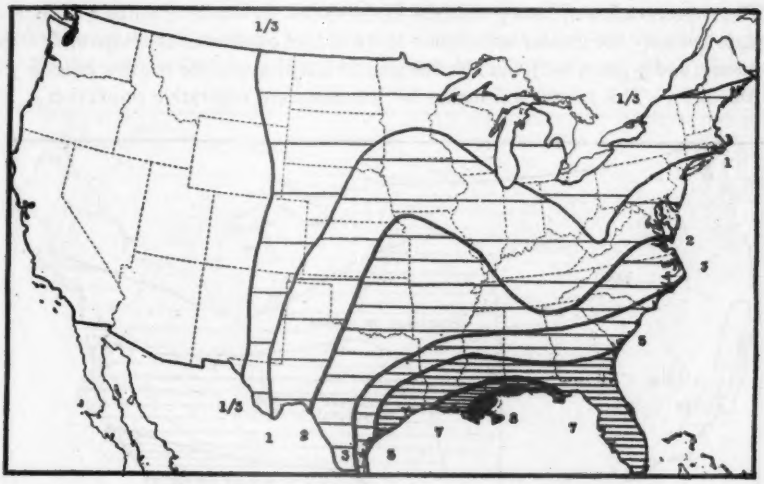

FIGURE 7.—*Number of days per average year having downpours of 1 inch or more of rain in 1 hour*

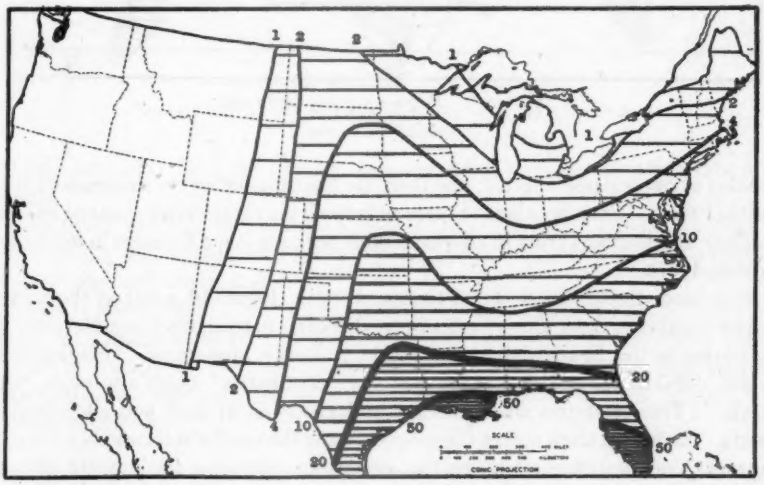

FIGURE 8.—*Relative frequency of downpours of 3 inches or more in 2 consecutive hours*
Times per century

rains per year; rare means that there was only one very hard rain during an average decade or longer. (In parts of the North and West, no such rain was officially recorded at the many regular, federally maintained Weather Bureau stations in the 30 years studied.) This map reveals a marked contrast with latitude in the East, but little regional contrast in much of the West. Very hard rains are much more frequent in the Southeast than in the North or West.

The concentration of heavy rainfalls in the South shown by Figures 3–9 helps to explain not only the greater soil erosion there (under conditions of comparable slope, exposure, and types of soil), but also the greater leaching and the relative infertility of porous soils. This poorer soil makes for less complete vegetative protection. The

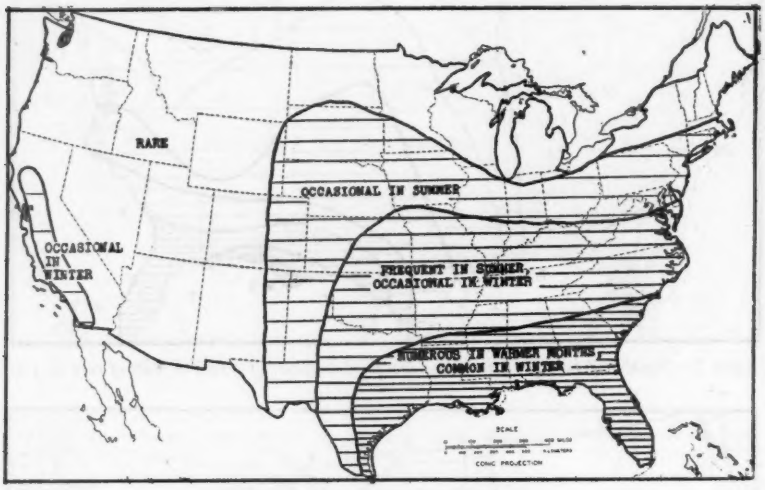

FIGURE 9.—*Frequency of very hard rains*
Defined in the text

flooding of rivers is also affected, and there are numerous other consequences (Visher, 1941b; 1942a). Even in as small a state as Indiana the considerable contrast between northern and southern parts in torrential rains helps explain differences in soil erosion (Visher, 1937).

Most hard rains are incidental to thunderstorms. Figure 10, a map of the average annual number of days with thunderstorm (Kincer, 1941), shows a considerable concentration in the South and in the Southern Rocky Mountains. Gullying is, of course, notably augmented by thunderstorm "cloudbursts" which also cause "flash floods." Thunderstorms are significant geologically in at least two additional respects. Lightning often strikes the ground, fusing the sand or soil curiously or cracking rocks, and sometimes starts fires that change the vegetation significantly, often for long periods. The soil is also affected by severe fires. Lightning-induced fires in outcropping lignite beds of the northern Great Plains have caused some of the unusual rock conditions and colors in the Little Missouri River Badlands.

Thunderstorms are significant geologically also in their effect upon rock disrupture. A large share of the thunderstorms occur during the heat of the day, shortly after sunshine has heated exposed rocks. The rain from thunderstorms is characteristically rather cold, indeed often almost ice cold—hail is common. The sudden fall of the cold rain upon the hot rock surfaces is a potent cause of their disrupture. Examples of breaking of "desert pavement" rocks by the rain from local thundershowers are

given by Walther from North Africa, and sharp, expressive noises caused by the breaking of stones were heard by the present writer near Tucson, Arizona, in July and August 1909. This writer has seen several very large exposed glacial boulders

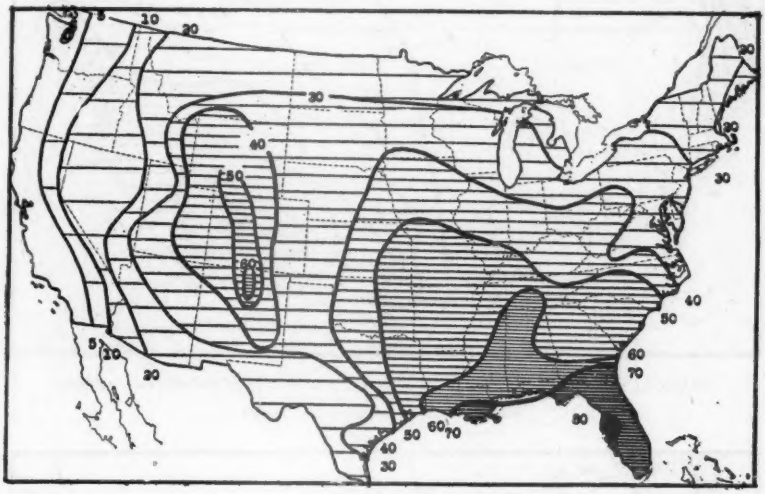

FIGURE 10.—*Frequency of thunderstorms*
Number of days per year having one or more thunderstorms

that had obviously been cracked by lightning, in South Dakota, Minnesota, and Indiana.

Some squall winds (a part of most thunderstorms) are violent enough to break or uproot trees. The squalls, which come before the rain falls, frequently pick up considerable dust and scatter it widely.

Figure 10 shows that thunderstorms are relatively scarce near the Pacific Coast and are far more common in New Mexico and Colorado than in Montana and Idaho. Presumably comparative studies of exposed points, such as mountain tops, in those areas will disclose differences in rock fragmentation correlated with the differences in thunderstorm frequency.

GROUND-WATER RECHARGE

The volume of water which enters the ground varies with the amount of precipitation and its time and rate of fall, as well as with local surface and ground conditions. Precipitation during the cooler months is much less likely to evaporate soon than is that which falls during the warmer months. Moreover the intensity of fall is less in the cooler months than in "the thunderstorm season," and hence more moisture has time to enter the ground. Consequently, Figures 11 and 12 help explain Figures 13 and 14, and throw considerable light upon contrasts in the amount of ground-water supplies in areas where mantle rock and slope conditions are comparable.

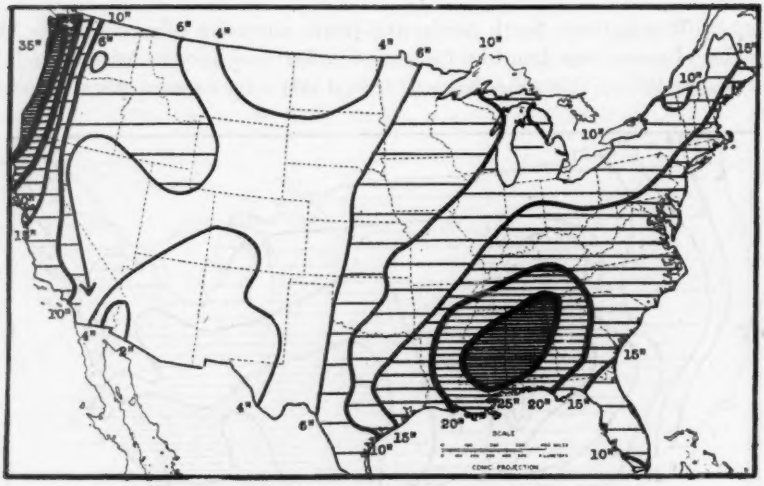

FIGURE 11.—*Average precipitation totals during season of chief ground-water recharge* December–April inclusive; in inches

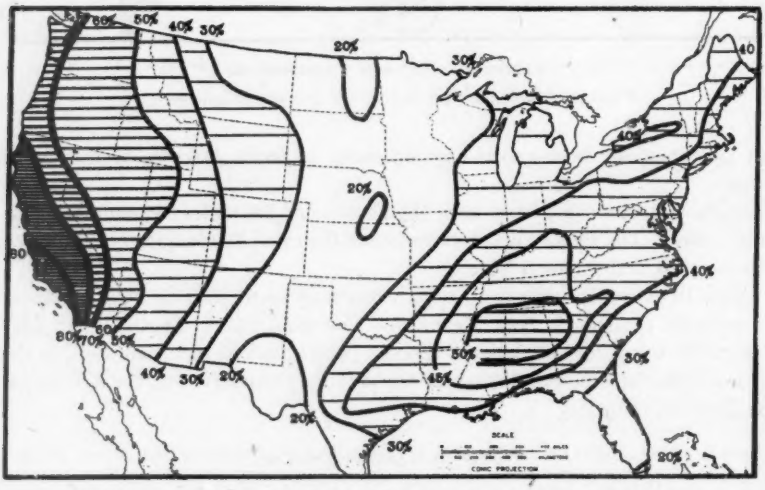

FIGURE 12.—*Percentage of annual precipitation occurring in December–April*

Figure 11 gives the average precipitation during the 5 months, December to April inclusive, when the ground-water supplies are most likely to be augmented. This original map shows that much of the East receives about three times as much precipitation in these months as is received in much of the West, except in the Pacific States. The total received in much of the Southeast is more than five times as great as in most of the Southwest.

Figure 12, of the per cent that the December to April precipitation is of the annual

precipitation, reveals that this 41 per cent of the year receives more than 41 per cent of the annual precipitation in the western fourth of the country and in a belt extending from eastern Texas to eastern Maine. The part of the country where the percentage is highest, southwestern California, is notable for the importance of its ground-

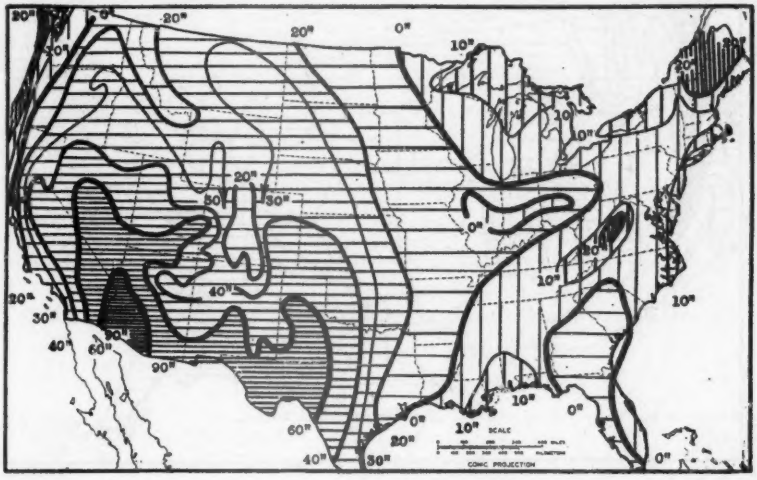

FIGURE 13.—*Differences between annual average precipitation and evaporation*
Evaporation in excess, horizontally lined; precipitation in excess, vertically lined; in inches

water supplies. The large ground-water supply in the Los Angeles Basin is due largely to topographic and geologic conditions, but the time of the rainfall is a significant influence. In the broad central zone, from North Dakota to western Texas, where these critical 5 months receive only about half their proportionate share of the annual precipitation, ground-water supplies are renewed only slowly, and pumping has lowered the water table badly in most localities. Conversely, shallow wells have been lowered notably less seriously in most of the East.

PRECIPITATION VERSUS EVAPORATION

Figure 13, a map of the difference between the average annual amounts of evaporation and precipitation, is a shaded copy of one by Meyer (1942). In most of the East and in a small part of the Northwest (shaded vertically on the map) precipitation normally exceeds annual evaporation from water bodies. In more than two-thirds of the country, however, the annual evaporation from water bodies usually exceeds normal precipitation. The excess is more than 90 inches a year in the lower Colorado River valley. The regional contrasts shown by this map help to explain average soil dryness, and hence the availability of wind-blown materials. Also partly explained by these contrasts are many of the differences in mineral content of the soil and of water. (Alkaline soils and saline lakes are found only where evaporation normally exceeds precipitation.)

The contrasts in evaporation as compared with precipitation also help govern the type and density of vegetative cover. The Rocky Mountains have much exposed rock as compared with the Appalachians partly because the evaporation rate normally exceeds precipitation in the Rockies while the reverse is true in the Appalachians.

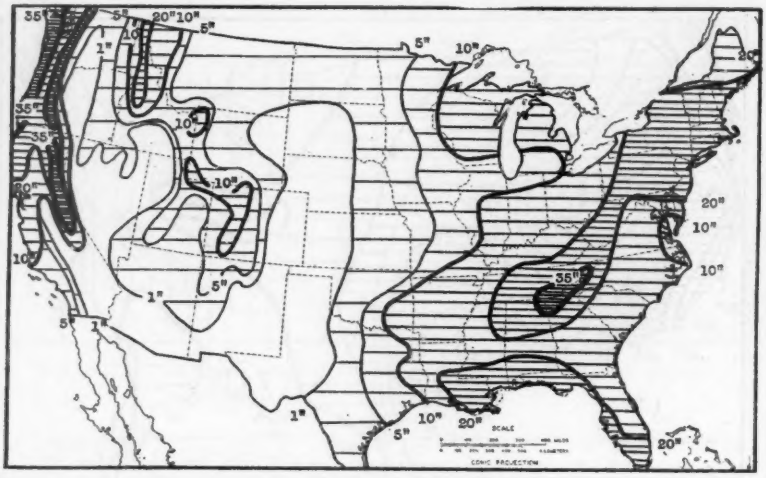

FIGURE 14.—*Average annual runoff*
In inches

RUNOFF

Figure 14, a map of the average annual runoff, is a shaded, somewhat simplified copy of a National Resources Board map. A sharp regional contrast in runoff correlates with the previous maps and with contrasts in slope, total annual precipitation, temperature, and various other conditions. In about one-fourth of the country the annual runoff averages less than 1 inch of water. On the other hand, a North Pacific area (the Cascades and northern Coast Ranges) and a part of the southern Appalachians have a runoff in excess of 35 inches a year. The amount of runoff determines the size and number of streams and, of course, profoundly influences the rate of erosion. The average slope is also affected. In general, in otherwise comparable areas, the number and length of contour lines needed to show the topography accurately increase with the average runoff. This is despite the fact that cliffs decrease in frequency and height with increase in runoff (Visher, 1941a).

The duration of snow cover (Fig. 15) is of geologic interest partly because a snow blanket reduces frost action and soil erosion. Within the United States, sizable southern and southwestern coastal zones have snow cover (1 inch or more) less than 1 day a year. By contrast a rather large northern zone is snow-covered for more than a third of the year. The greater erosion in the South upon otherwise comparable slopes correlates with the duration of snow cover as well as with rainfall intensity and runoff. This map is a shaded copy of a recent federal map (Kincer, 1941).

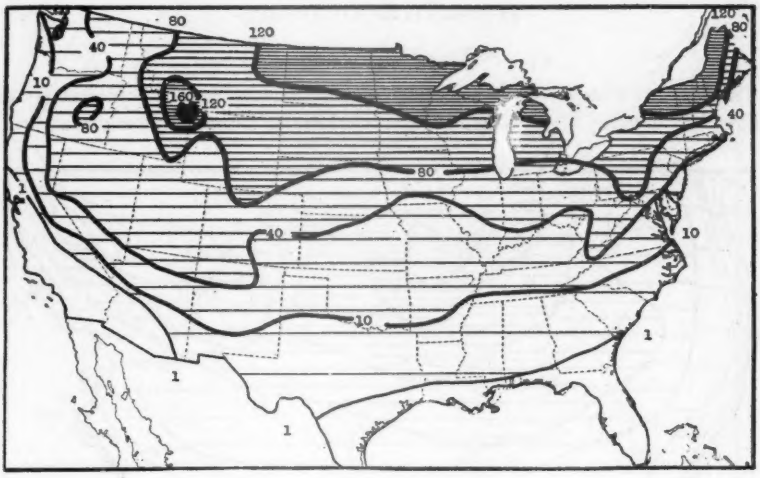

FIGURE 15.—*Duration of snow cover*
Days per average year

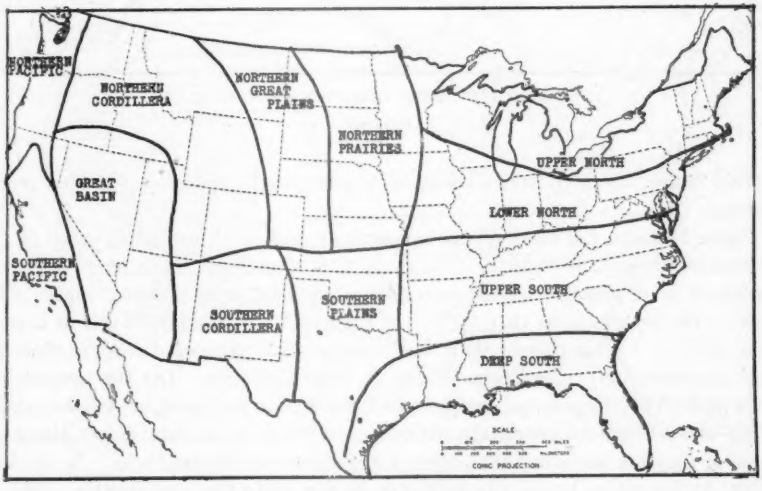

FIGURE 16.—*Precipitation regions*
Based on many sorts of data

PRECIPITATION REGIONS

The final map of this precipitation series (Fig. 16) is an original one of precipitation regions. These regions are described and differentiated at some length elsewhere (Visher, 1942b). Various geologic processes differ appreciably in intensity in these several regions.

TEMPERATURE CONDITIONS

ANNUAL AND DAILY RANGE

Temperature conditions are obviously of geologic significance both directly and indirectly. Figures 17–29 illuminate the considerable temperature contrasts in the

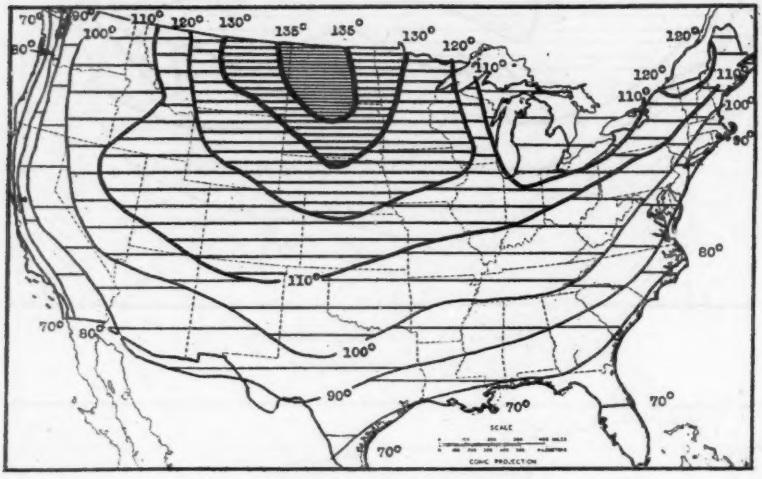

FIGURE 17.—*Average annual temperature range*
Degrees F.

United States, which contrasts influence various geologic processes and their consequences.

Figure 17 shows the mean annual temperature range. It is original, based on the records of 40 years, 1899–1938. The range from the highest shade temperature experienced in an average summer to the lowest reached in an ordinary winter is for most of the country more than 90°F. In much of North Dakota this range is more than 135°F. A range of even 90°F. in the shade subjects exposed rocks to considerable expansion and contraction, helping in their disruption. (As the temperature data presented in these maps, or upon which these maps are based, are those recorded in the shade of official instrument shelters at an elevation of about 5 feet above the ground, they are less sharp than those which occur on exposed rocks. In the sunshine, dark surfaces become much hotter by day and often considerably colder at night than the official shelter temperatures which are available.)

Figure 18, an original map of the extreme range experienced in 40 years, shows that only near the Pacific and Gulf Coast is the shade range less than 100°F., while in a sizable northern Great Plains area it is more than 175°F. (from colder than −60°F. to above 115°F.). Little of the world has greater extreme ranges of shade temperatures.

Figure 19, a map of the average daily range of temperature in Weather Bureau shelters, is also original. The daily range of temperature is less varied in most of the

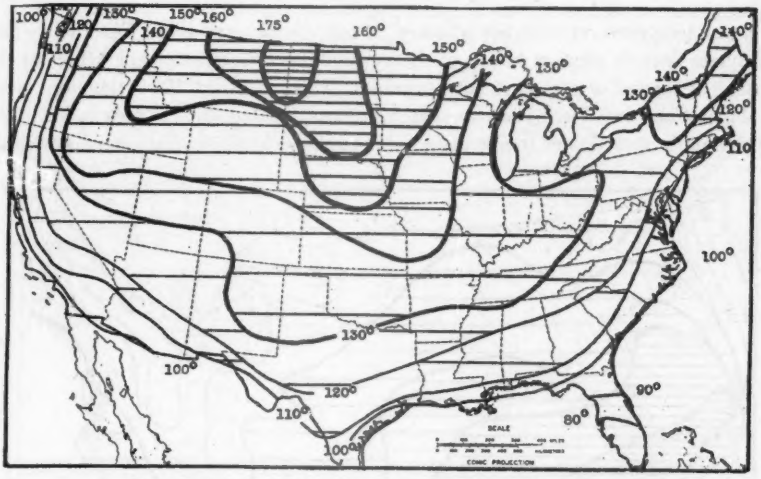

FIGURE 18.—*Extreme temperature range experienced in 40 years*

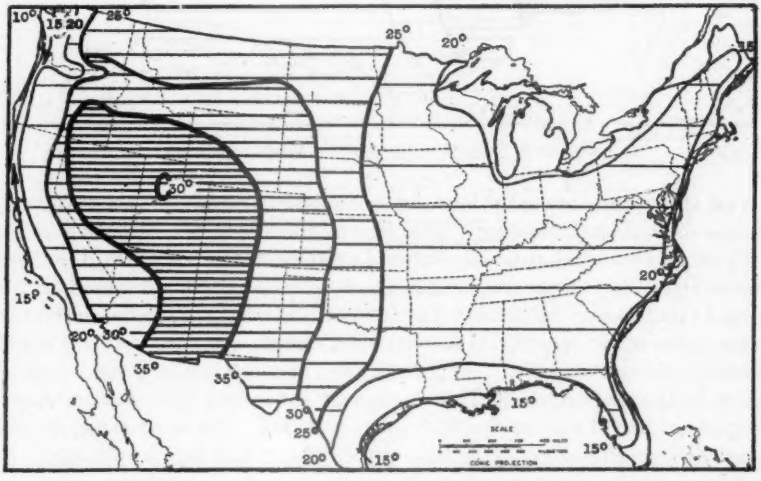

FIGURE 19.—*Average daily temperature range, in the shade*

country than is true of the other climatic conditions here considered. Aside from a narrow coastal fringe where the range is less than 20°F., the average daily range for most of the eastern half of the country is between 20° and 25°F., while in most of the West the range is between 25° and 40°F. In clear weather the daily range normally is fully 50 per cent greater at ground level even in the shade than the averages shown here which are based on both clear and cloudy conditions. Of course the soil and rocks become much hotter in the sunshine than in the shade, while at night they cool

to lower temperatures than are attained in near-by covered areas, like the shelter. Adequate data to prepare a map of the average daily range of temperatures at the surface of the soil or rocks are not available. This map (Fig. 19) is therefore given as the best now feasible. It shows that, insofar as disintegration of rock is due to the normal daily variation of temperature, such rupture should be distinctly more rapid

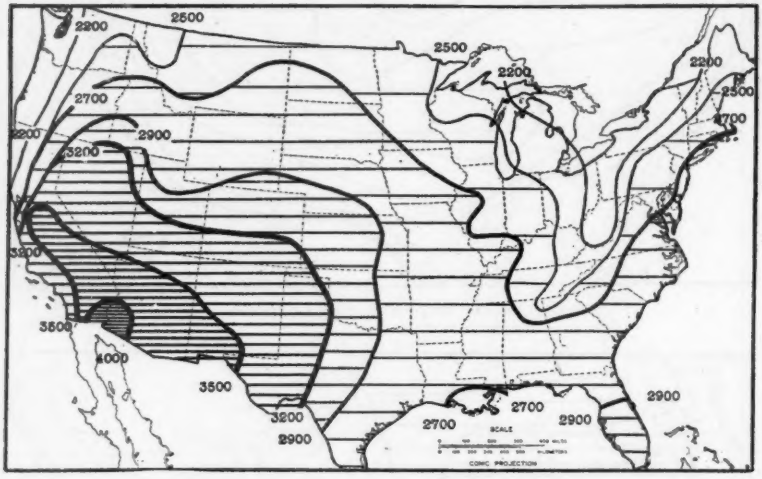

FIGURE 20.—*Sunshine, average annual number of hours*

in most of the West than in the East and should be least rapid along the coast, where, because of abundant atmospheric moisture and greater fog, the daily range is least.

Figure 20, an original map of the hours of sunshine, shows that much of the Southwest receives about 50 per cent more hours of sunshine a year than does much of the Great Lakes region or the northern Pacific coast. Much of the sunshine in the Great Lakes region comes, however, in summer when the sun's rays are relatively effective in heating the rocks and soil. The geologic effect of the regional contrasts in sunshine shown by this map are chiefly indirect, through their effect upon the daily range of temperature and of evaporation, and upon vegetation. The south-facing slopes are less densely vegetated partly because of their higher mid-day temperature. Normally they are less steep than otherwise comparable north-facing slopes in response to a combination of conditions discussed elsewhere (Visher, 1937; 1941a).

Frost action is of profound geologic importance. Figure 21 shows wide regional contrasts in the average number of nights during which freezing temperatures are recorded in the Weather Bureau shelters. At ground level in the open, frost occurs more often than here shown. Where the annual totals are not large, scattered observations reveal that frost occurs on at least a fifth more nights than Figure 21 indicates. Another inadequacy of this map is that the Weather Bureau stations upon which it is based are nearly all situated at relatively low altitudes, not on the mountains or even on high hill tops. This is a shaded copy of a colored official map (Kin-

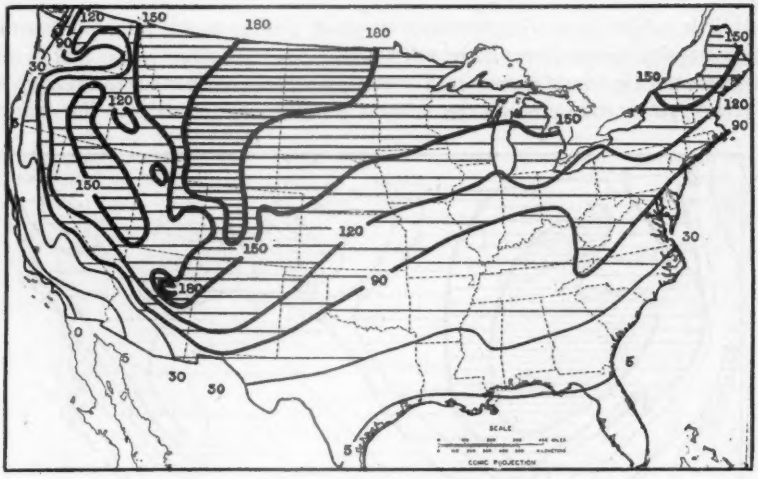

FIGURE 21.—*Frost at night, average number of times per year*

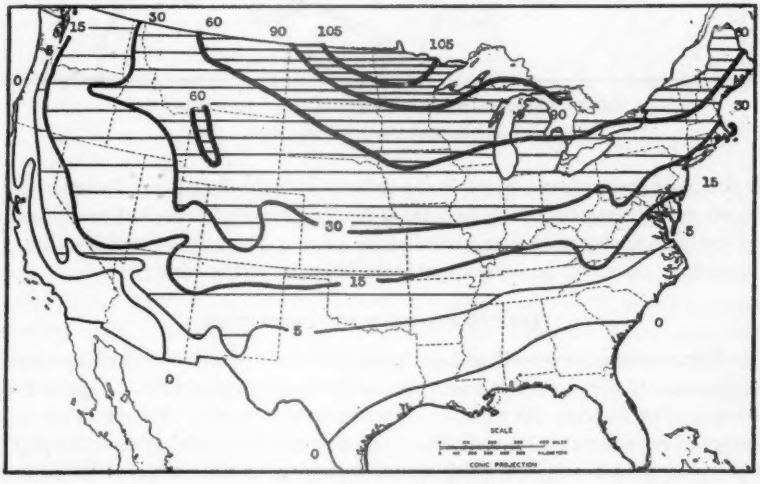

FIGURE 22.—*Freezing days*

Days per normal year with the temperature constantly below 32° in the shade

cer, 1928). Frost occurs rarely near the Gulf of Mexico and Pacific Ocean but occurs on more than half the nights in the year in a sizable north-central area.

Figure 22, from the same source as Figure 21, shows that the temperature is continuously below freezing, in the shade of the Weather Bureau instrument shelter, on fewer than 5 days a year in most of the South and Far West but during more than 60 days in much of the North. Of course while the ground is continuously firmly frozen

it is little subject to erosion by water or wind. However, wind erosion occurs at below-freezing temperatures if the soil is dry, not cemented by ice. (This is often the case except in humid regions.) The marked regional contrasts in the average rate of erosion partly correlate with the duration of freezing temperatures. For example,

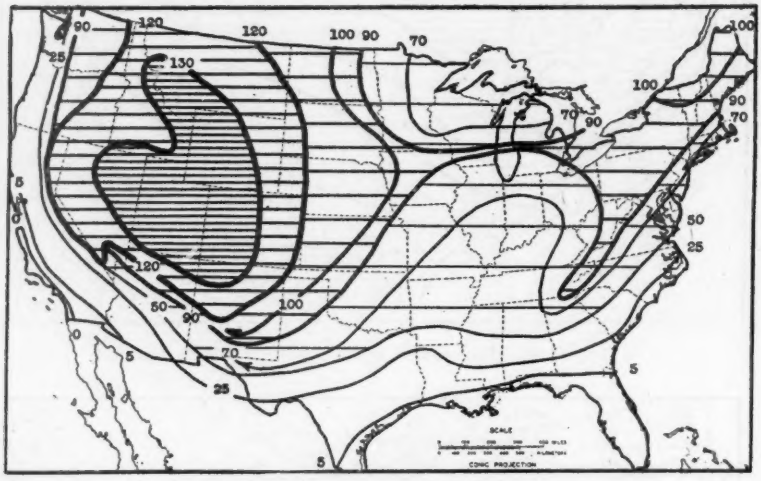

FIGURE 23.—*Average annual number of times of freeze and thaw*
Night frost minus freezing days

the drainage basin where erosion is the slowest is in the Red River Valley of North Dakota and Minnesota, chiefly because of topographic conditions, but partly because it is firmly frozen for more than a third of the year. (There the ground is so firm that automobiles can safely go cross country during most of the winter.)

FREEZING AND THAWING TEMPERATURES

A climatic factor of special geologic interest is the frequency of the alternation of freezing and thawing temperatures, the number of swings past 32°F. Figures 23 and 24 attempt to indicate the regional contrasts in this factor. Figure 23 shows the number of days per average year when temperatures alternate between freezing and thawing (secured by taking the difference between the number of days with minimum temperatures below freezing (Fig. 21) but maximum often above freezing, and the number on which maximum temperatures are below 32°F.—that is, freezing temperatures prevail all day (Fig. 22). Near the Gulf of Mexico and in southwestern California only about 5 days a year have an alternation of freezing and thawing on this basis (Fig. 23). By contrast, a large western area has such an alternation during more than a third of the days of the year. The frequency of freeze and thaw increases northward from the Gulf to southern Michigan and Wisconsin and then decreases northward, in response to the increase there in the number of days continually below freezing (Fig. 22). As the frequency of freeze and thaw is of conspicuous geologic

interest, a second effort is here made to discover the regional contrasts therein. Figure 24 is based on the total number of days with daily shade temperature normals or means between 20°F. and 50°F. (Visher, 1943b). As the normal daily range of temperature (Fig. 19) is about 25°F. for most of the country, a place which has a daily

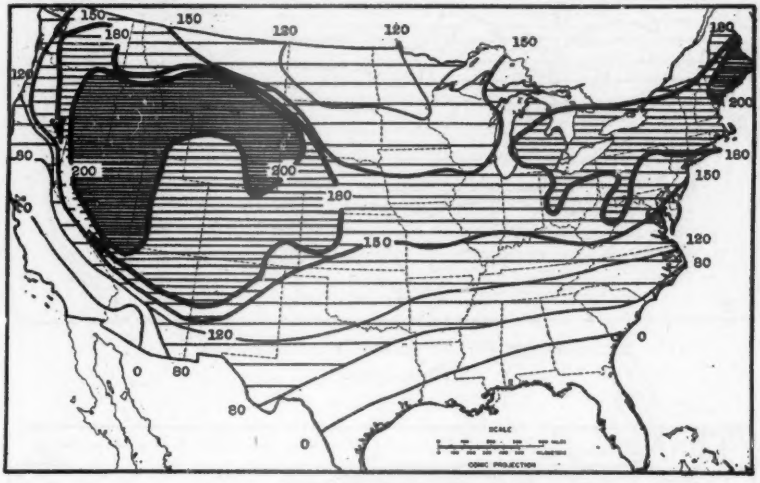

FIGURE 24.—*Frequency of freeze and thaw*

Based on daily temperature normals and on average daily range, times per year

normal of 25°F. clearly normally experiences a fluctuation above and below 32°F. Conversely when the daily average temperature is 45°F., normally the downward fluctuation usually passes the freezing point. Cloudy days and nights which have means near 20°F. or near 50°F. would not have both freeze and thaw, but in clear weather, some days with means below 20°F. and some above 50°F. would have both freeze and thaw. (Indeed not rarely in clear weather, when the shade temperature is somewhat below 15°F., a little melting takes place in south-facing slopes, especially late in winter.) As the Northeast is relatively cloudy in winter, this map (Fig. 24) shows too many freeze-thaw days there. The number shown in Figure 24 for the West is probably less than the actual number. This is partly because of the greater sunshine there, but the higher average elevation helps, as, where the air is thin, solar heating and nocturnal cooling are greater than at lower elevations.

These two freeze-thaw maps show wide regional contrasts in the frequency of frost action. Undoubtedly some of the differences in the rate of rock weathering correlate with these contrasts. However, frost action depends upon the presence of water which can freeze, as well as upon freezing temperatures. In parts of the West, the rocks and their upper cracks are often dry, with the result that frost rupture is less rapid than might be expected from Figures 23 and 24. Freeze and thaw are also significant in sheet erosion, as it often renders the top of the soil fluffy—easily carried away by even a small runoff.

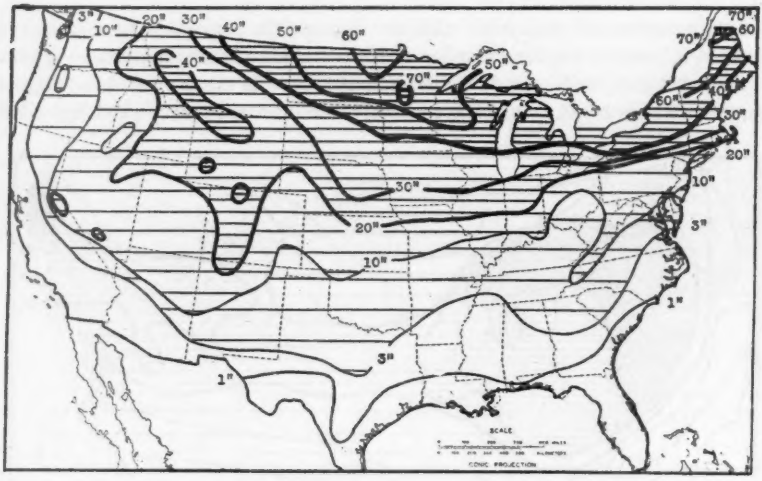

FIGURE 25.—*Average depth of frost penetration*
In inches

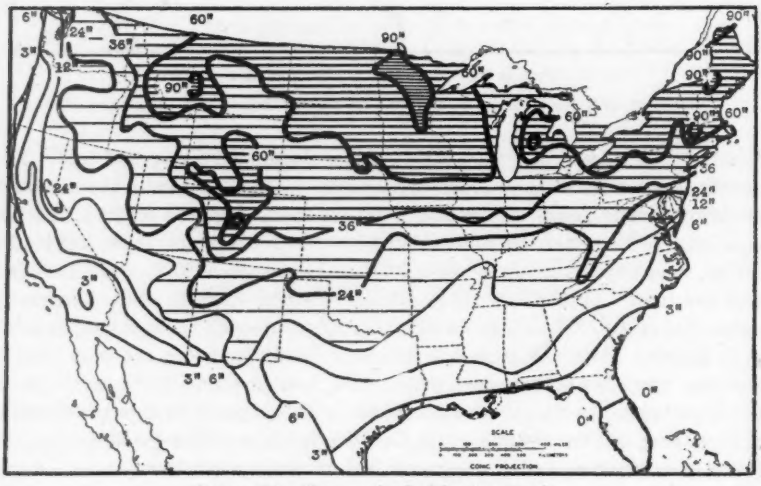

FIGURE 26.—*Extreme depth of frost penetration*
In inches

FROST PENETRATION

Figure 25 shows the average depth of frost penetration. It is a shaded copy of a Weather Bureau map (Kincer, 1941). On the average, frost penetrates less than 3 inches in the Deep South and on the Pacific Coast but more than 30 inches in much of the North. In northern New England and in northern Minnesota it usually penetrates more than 60 inches. The maximum depth of frost penetration (Fig. 26) is

about twice as great as the normal penetration, except in the coldest areas, where the penetration is about 50 per cent more than the normal. This map (Fig. 26) is based on scattered data compiled by the Weather Bureau.

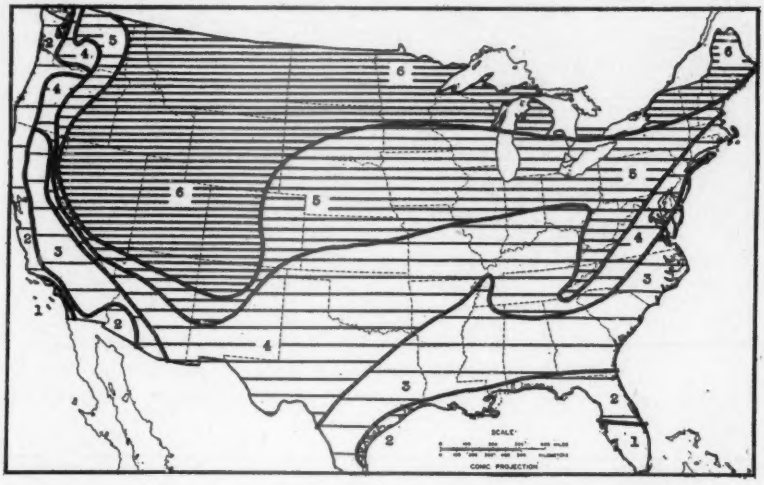

FIGURE 27.—*Regions based on the duration and severity of freezing temperatures*

(1) Nearly always warm or hot, frosts almost lacking; (2) No real winter, but frosts are fairly frequent and freezes occasional; (3) Mild winter; soil usually freezes 1–4 inches, but 7 or 8 months are usually frostless; (4) Brief but real winter, soil freezes 6–18 inches, frosts occur during 5–7 months; (5) Cold winter, soil freezes 18–36 inches, only 3 or 4 months without freezing, minima often 10°–20° below zero; (6) Long winter, much cold, soil freezes 3–6 feet, frosts in all months or in all but 1 or 2; minima often −20° or lower.

These two frost-penetration maps are of geological interest in at least three respects: They throw evidence upon how deep the formation of ice in cracks may split buried rocks; they reveal something of the regional contrast in the strength of the frost's heaving action, by which loose stones, as in glacial clay, are worked to the surface; they also give evidence on the regional contrasts in the amount of ice on rivers, lakes, and ponds. Such ice is an important influence in modifying the shores and in increasing the destructiveness of flooded streams.

TEMPERATURE REGIONS

Figures 27, 28, and 29 show three sorts of temperature regions. Figure 27, regions based on the duration and severity of freezing temperatures, is a copy of Map 17 of a study of freezing temperatures in the United States (Visher, 1944a). The six regions, briefly characterized in the legend, differ appreciably, but, of course, the boundaries are transitions, not narrow lines. Figure 28 shows temperature regions on another basis. It is a considerably simplified shaded copy of an official map recently sent by Kincer. The unit upon which Figure 28 is based is known as a degree-day. Daily average temperatures of 65°F. or higher are ignored. An average of 64°F. is 1 degree-

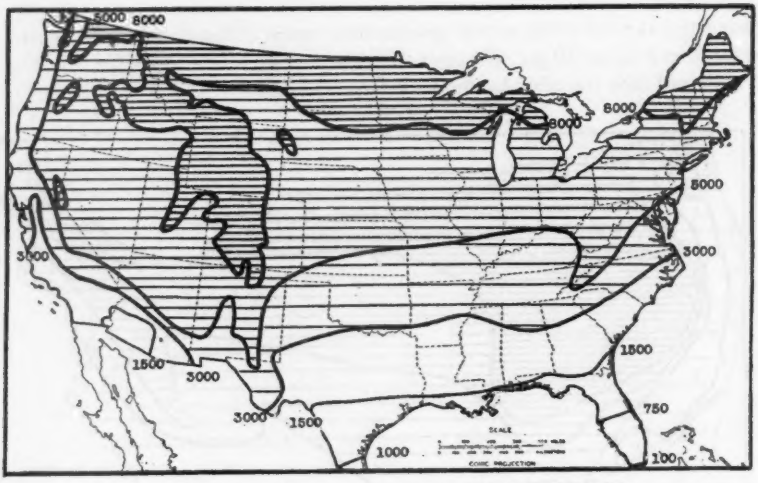

FIGURE 28.—*Contrasts in the amount of temperatures below 65°*
Degree-day units. A day with an average temperature of 64° is 1 unit; one of 50° is 15 units

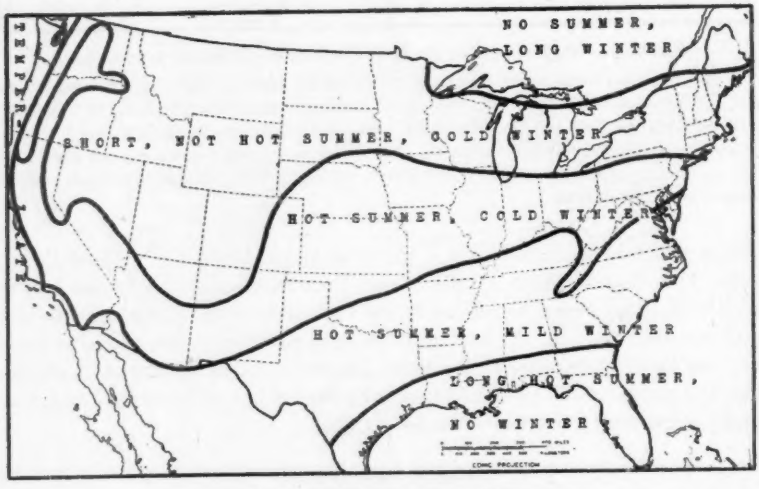

FIGURE 29.—*Temperature regions*
Based on daily normal temperatures, and the duration of very hot, hot, warm, mild, cool, cold and very cold conditions

day unit; a daily average of 50°F. is 15 units, a day which averages 0° is 65 units. This map is of interest to geologists in two chief ways. It suggests the amount of fuel required to maintain comfortable house temperatures. For example, it indicates that, with comparable insulation and wind, several times as much fuel is needed near

the northern as near the southern margins of the country, except on the Pacific Coast. Similarly, it indicates that in the South most days are too warm for comfortable field work, if 65°F. is considered a comfortable average temperature. (This means about 78°F. in mid-day.) Conversely, in the North and West a considerable fraction of the year is too cold for effective field work.

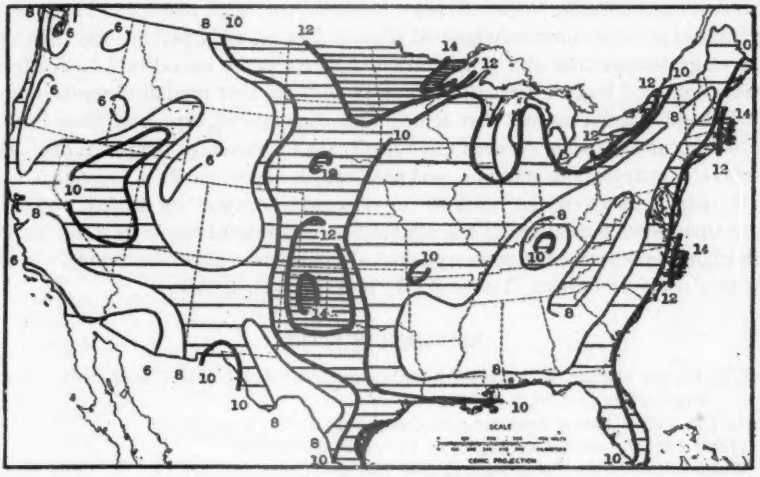

FIGURE 30.—*Average wind velocity*
Miles per hour

Figure 29 presents the temperature regions in a more conventional manner. Of the six regions it shows, only one, on the Pacific Coast, can reasonably be called temperate; most of the country is quite intemperate. These temperature regions correlate significantly with vegetation types, including agriculture, and with chemical as well as mechanical weathering. An elaboration of some of the differences between these six regions is given elsewhere (Visher, 1943b).

WIND VELOCITY

The final map (Fig. 30) is of average wind velocity, in miles per hour, and is a shaded copy of a colored Weather Bureau map (Kincer, 1928). Average wind velocities are relatively high on the Atlantic Coast and on the shores of the Great Lakes, in both of which areas, in favorable situations, sand dunes are well developed or wave action is prominent. In the interior, the wind velocity is relatively great in "the Dust Bowl" of the Great Plains, from which area vast quantities of dust are occasionally wafted eastward. The relatively low wind velocities in much of the West do not, however, indicate little wind action there. The numerous dust whirlwinds of that region pick up much dust. The average wind velocity is relatively low there partly because, as a result of the nocturnal stoppage of local convection due to the rapid cooling after sundown, characteristic of dry regions, a surface calm commonly develops at night, except where the slope is such as to permit down-slope air drainage.

SUMMARY

The regional contrasts within the United States in average precipitation and average temperature, the aspects of the climate commonly considered to be of geologic significance, are little or no greater than are the regional contrasts in several other climatic factors, here considered—torrential rainfall, snow cover, evaporation, temperature range including freeze and thaw, sunshine, and wind velocity. The geologic significance of these commonly ignored climatic factors, while perhaps less than that of average temperature and precipitation, appears to be considerable. Scattered observations and limited comparative studies indicate that rainfall concentration is clearly highly significant and that temperature fluctuations, especially those involving freezing and thawing, are even more significant than average temperatures. The influence of evaporation, sunshine, and wind are also appreciable.

The maps here given, the notes on the regional contrasts they display, and comments upon some indications of the significance of the variations may throw helpful light upon various regional geomorphological contrasts. This was found to be the case in a study of Indiana (Visher, 1937; 1941a; 1942a; 1944b).

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USE OF MICROLITHOLOGIES AS ILLUSTRATED BY SOME NEW YORK SEDIMENTARY ROCKS

BY HAROLD L. ALLING

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ABSTRACT

This paper, based upon petrographic studies of 782 thin sections of sedimentary rocks, chiefly from New York State, describes laboratory techniques and graphic representations which place the lithology of sediments upon a quantitative basis. Microscopic (Delésse-Rosiwal) analyses, which provide the amounts of the constituent minerals, are rearranged on the principle that the kind of

minerals, their size, and their orientation are responsible for the shaly structure of many rocks. Taking this into account, the mineral composition is recalculated into the terms of three microlithologies as three "end members." Plotted beside geologic columns, these reveal the alternating, rhythmic, and periodic sedimentation.

Microlithologies of fossiliferous sediments furnish a clue to "facies control." Certain fossils are confined to rocks with a narrow compositional range.

The Clinton iron ores were originally limestones which, as part of their lithogenesis, were replaced by iron, provided solutions of iron were available and the argillaceous microlithology was under 9 per cent by weight.

The term "shale" is best reserved to express the structure of sediments. The fundamental factors producing shales are the orientation of the constituent minerals, their minute grain size, and the presence of clay or claylike minerals with pronounced cleavage which coat minerals such as quartz, preventing their angularity from interfering with the ability of the rock to split.

Plotting of the lithologic properties of rocks in terms of three microlithologies gives quantitative values to the terms massive, platy, flaggy, heavy-bedded, thin-bedded, and fissile.

Grain sizes of quartz increase with the increase in the amount of the siliceous microlithology. The amount and the grain size of recrystallized carbonate increases with the decrease in the amount of the argillaceous microlithology of limestones.

INTRODUCTION

This paper is an attempt to devise laboratory methods to place the lithology of sedimentary rocks on a quantitative basis in terms of three "end members" for the purpose of plotting it beside stratigraphic columns. Many of these techniques and schemes have been used by mineralogists, igneous rock petrographers, and petroleum geologists. They are here used with modifications and adaptations to this specific purpose. Sedimentary petrographers, such as Krynine, are using them with great success (Pirsson and Schuchert, 1924). The materials studied were Paleozoic sediments chiefly of New York State in the form of 782 thin sections.

Figures 4–6 furnish information, probably not obtainable in any other way, regarding details of alternations and cyclic rhythms or sedimentation, something of the environment of certain fossils, and the kind of limestone that by replacement became the Clinton iron ores.

What was sought was a quantitative concept of the field term "lithology." By this stratigraphers express the appearance, composition, grain size, degree of shaliness, and character of weathered surfaces, etc. These, however, are not strictly independent variables. Delésse-Rosiwal analyses (either by volume or weight percentage) give the approximate mineral composition in terms of the mode, but the lithology of sediments is more than that. The relationship among the factors was investigated.

"Lithology" is a megascopic term. As determined by quantitative microscopic means, it becomes "microlithology." At first the term "microfacies" was considered but was later discarded because of the difficulty of framing a satisfactory definition of "facies," and especially of the new term "microfacies" (Brown, 1943, p. 325; Calkins, 1943, p. 608–608; Campbell, 1944, p. 70–71) which has been proposed and carries a different meaning from that used here.

ACKNOWLEDGMENTS

The collecting of measured specimens for thin sections began in April 1923, with the field assistance of Merle K. Alling. The following former students helped furnish additional material: Bernard H. Dollen, Virginia Hoyt Jones, Arthur S. Gale, Jr., Tracy Gillette, William L. Grossman, John T. Sanford, Lois Kremer Sharpe, Charles

M. Reed, and Marguerite Smith Robertson. Many of the above were helpful in field and class discussions.

Through the courtesy of Mr. J. T. Fetherson of Cuylerville, New York, I secured a superb suite of subsurface specimens.

METHODS OF ANALYSIS

The slides were cut from rock specimens collected with complete data of the exact stratigraphic position and the orientation. Furthermore, they were collected close enough together, stratigraphically, to provide samples of all types of sediments within each stratigraphic unit.

Delésse-Rosiwal analyses, based upon intercepts, were made with a Wentworth stage. Repeated runs demonstrated that, while the accuracy is not high, they provide the mineral composition of rocks, which is obtainable in no other way. The errors of the Delésse-Rosiwal method are probably of the same order of magnitude as the errors arising from the use of thin sections as representative samples.

The size of the mineral grains was measured in terms of nominal sectional diameter (Wadell, 1936, p. 263) by the diaphragm method (Alling, 1941) in two dimensions. The size of the quartz grains was measured in all slides. The grain size of various kinds of carbonates was measured in many of the limestones.

FACTORS INVOLVED IN THE CONCEPT OF "MICROLITHOLOGY"

GENERAL CONSIDERATIONS

Other factors besides mineral composition are involved in the concept of microlithology. These were ascertained through microscopic examination. Some of these are definitely recognized and are discussed as follows:

A small amount of clay lubricates the minerals so that a preferred orientation of mineral grains and a lack of cohesion result in the structure called shaly, provided the grain size of the nonclay minerals is small. Minute quartz grains in a sediment with a clay content are usually so thoroughly covered by clay that they do not contribute to the grittiness of the rock but they act like clay. On the other hand, larger grains of quartz, even though they may be partially coated by lubricating clays, usually possess sufficient angularity to make the rock more massive. The amount of clay and the size of the quartz grains are interdependent in their effects. This relationship is established to my complete satisfaction but is not as yet quantitatively measureable.

Another factor is the nature of the carbonates. It was possible to recognize and quantitatively measure the amounts of the following: (1) fossils and fragments thereof, (2) recrystallized, and (3) minute grains considered to be detrital or clastic (Field, 1919; 1931; Thorp, 1934; Trask, 1932).

The rhomboidal shape of calcite and dolomite contributes to the coherence of the rock, especially in recrystallized limestones. In contrast, small grains of carbonate, coated by unctuous matter, behave like clay. But because the small grains of carbonate are usually aggregates without interstitial clay, clastic carbonate in a clay-bearing sediment is less effective in producing shaliness than is an equal amount of

small quartz grains. Here also the quantitative relationships are imperfectly known, but the principle seems to have been substantiated.

Calcitic paste or lithified lime mud, which may be in part precipitated, usually occurs in the limestones of New York which have a low clay content and in general seems to function like the other carbonates. Hence lithographic limestones composed of small grains without clay are usually massive.

Clay minerals in many "red beds" have adsorbed iron compounds. This seems to reduce the unctuousness of the clay. This is difficult to check microscopically as the quartz grains in such rocks are not necessarily small and are usually angular, producing a less shaly rock.

Chert occurs in some of the limestones analyzed. Chert seems to be indigenous in such rocks, so it was assigned to the calcareous end member. The clastic quartz content is usually low. The difference in origin seems to justify placing chert in a different microlithology.

Further assistance in developing the concept of microlithologies was obtained by studying rocks that approached as closely as possible the end members. Some highly fissile shaly beds contain a very high clay content: limestones, nearly all carbonates, and siliceous rocks with dominant quartz. These served as standards to establish the microlithologies of the three end members. By thus using natural rocks one avoids the mistake of regarding the end members as 100 per cent clay, 100 per cent carbonate, and 100 per cent quartz.

As is well known, "pure" sandstones, such as the St. Peter, contain other minerals beside quartz. These minor minerals are just as much a part of the sandstone as is the quartz. In a like manner very fissile shales, in terms of minerals, are not all clay. Quartz grains, however small, are an essential part. Other slides reveal types of rock intermediate between these. Such rocks were interpreted as percentages of the extremes.

A conglomerate consists of grains of gravel or cobble size (Alling, 1943, p. 259–269) in a matrix of smaller grains of like or different composition. There are, therefore, two parts to the rock. Conglomerates are analogous to porphyritic igneous rocks composed of phenocrysts set in a groundmass of other minerals. The phenocrysts usually differ in composition from the groundmass. There are slides of sediments of intermediate composition that show the multiple nature of their make-up. A fine example of this is a specimen of red Grimsby siltstone from Cuylerville, Livingston County, New York. The rock is uniform except for wisps of a highly fissile shaly rock as micro-inclusions. These are large enough, however, so that both portions can be measured by the Wentworth stage. This is a composite rock. Other slides show similar conditions but on a more minute scale. Still other rocks appear to be microscopically homogeneous. Nevertheless the opinion persists that these are composite as well. There is considerable microscopic evidence that many rocks are composite.

Detailed observations in the field of beds which consist of rapidly alternating types, such as the Reynales and the Irondequoit limestones of Clinton age in the Genesee Gorge at Rochester, show layers of calcareous rocks with intervening shale partings

(Fig. 1). These rocks range widely in composition. The shale partings are essentially argillaceous rocks, while the limy layers near the base contain a good deal of clay which decreases in amount toward the top. A satisfactory explanation of the

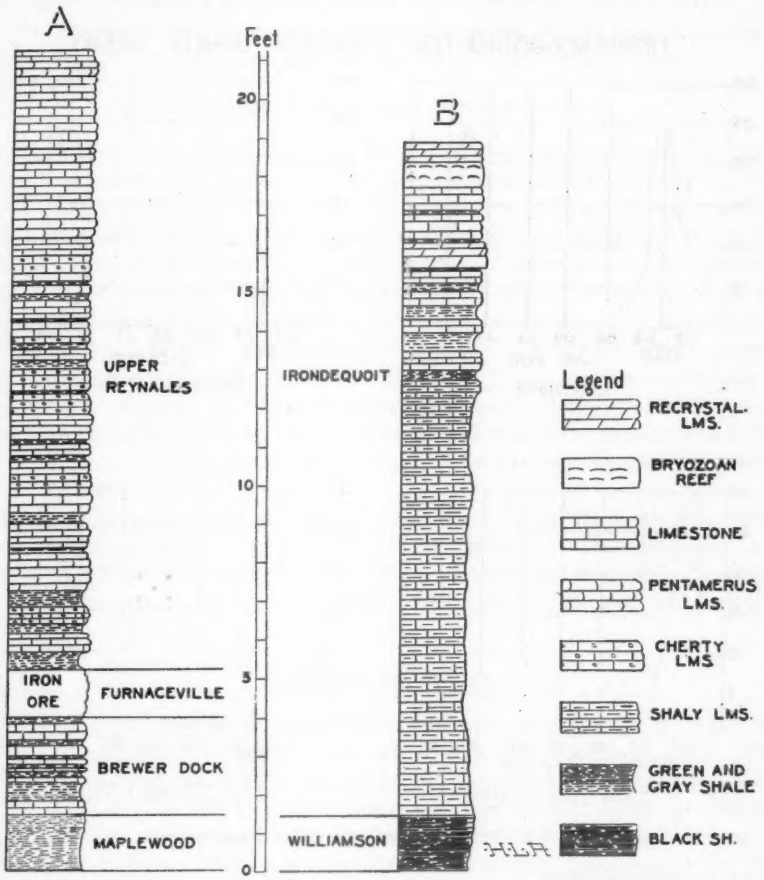

FIGURE 1.—*Two portions of the Clinton section at Rochester, New York*

Showing stratigraphic details in customary manner.

A. Upper portion of the Maplewood shale, and the following members of the Reynales: the Brewer Dock, the Furnaceville "iron ore," and the Upper Reynales.

B. Portion of the Williamson shale and the Irondequoit limestone.

field and laboratory observations is that they are composed of variable amounts of contrasting types of rocks.

Another line of evidence suggesting the composite nature of many sediments is based on a study of quartz frequency-distribution curves.

EVIDENCE OF MULTIPLE PEAKED CURVES

Many frequency-distribution curves of quartz grains are multiple-peaked, usually double (Fig. 2). Some have more than two modes. Various attempts—improve-

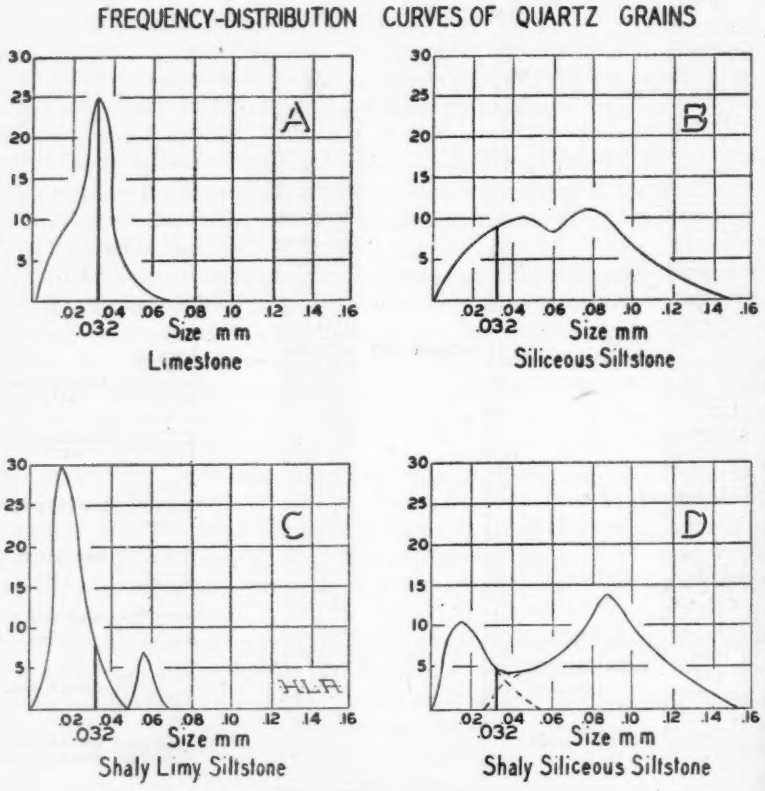

FIGURE 2.—*Frequency-distribution curves of quartz grains*

Frequency per cent against size.
A. Single-peaked, Lower Sodus limestone, Genesee Gorge, Rochester, New York.
B. Double-peaked, Thorold siltstone, Genesee Gorge.
C. Double-peaked, Brewer Dock member, Reynales formation. A shaly limy siltstone.
D. Double-peaked, Grimsby, Cuylerville, New York. Shaly siliceous siltstone.
The curves are divided into two parts by the line at .032 mm. The quartz, to the left, is assigned to the argillaceous, and to the right, to the siliceous microlithologies.

ments in technique, changing the number of class intervals, increasing the number of grains measured, etc.—were made to reduce the number of peaks. These were effective in a few cases, but most of the peaks persisted. The use of the statistical median would, however, obscure the presence of these critical sizes.

Slides consisting of two types of lithologies were given thorough study. Delésse-

Rosiwal analyses were made of the whole slide and of each type. Then the frequency of the quartz sizes of the same three units was measured. Curves, based upon the whole slide, showed two peaks. The per cent of the areas of the component parts of the curve corresponded to the percentages of the two lithologies (Fig. 2 D).

The presence of double-peaked curves of rocks which appear to be more homogeneous suggests that they too may consist of two or more lithologic types.

DEFINITION OF THE TERM "MICROLITHOLOGY"

The concept here proposed is based upon microscopic measurements. It recognizes that sediments range between the three extremes: from siliceous rocks, from limestones, to those rich in clay with a shaly structure. These extreme types are not monomineralogical but contain small amounts of other minerals that are just as much a part of the rocks as the dominant grains. Consequently a microlithology expresses the following concepts: (1) It is a natural assemblage of minerals, based upon actual rocks; this is the compositional part of the meaning. (2) Size of grains of the quartz is not an independent factor when clay minerals are present, because small grains of clay-coated quartz behave like clay. Clastic carbonate acts similarly but to a lesser degree. So the size of grains of quartz and clastic carbonate in a clay-bearing rock is a factor. This size-clay concept is likewise based upon natural rocks. The combination of the mineral composition plus the size-clay concept constitutes a microlithology.

Since rocks range in composition and in shaliness among three extremes, many rocks can be expressed in terms of three microlithologies. "Microlithologies" are like many igneous rock terms, conveying several fundamental concepts. For example, "granite gneiss" means composition, size of grain (texture), and foliation (structure).

NAMING THE END MEMBERS

Each of the end members was named for convenience. Scientifically this is difficult to do. It is impossible to find terms against which no objection can be raised. The names selected and used are old familiar terms; they are essentially compositional in meaning. But as here employed they express the clay-size factor in addition. "Calcareous" is satisfactory if dolomites are included. "Argillaceous", of course, refers to clay rocks. "Siliceous" was chosen rather than "arenaceous", for the latter was used by Grabau (1913) with a size connotation which it was desirable to avoid.

PRINCIPLES UNDERLYING CALCULATING MICROLITHOLOGIES

There is no serious difficulty in arranging the constituent minerals of sandstones or limestones; it is the rock with a shaly structure which requires special consideration, as has been discussed. Consequently the minute fragments of quartz are allocated to the argillaceous microlithology, when there is an appreciable amount of clay. Small grains of feldspar act in the same manner and are similarly assigned under the same conditions.

TABLE 1.—*Summary of calculating microlithologies*

Mineral	Argillaceous	Calcareous	Siliceous
Large grains of quartz*	—	—	X
Small grains of quartz	X	—	—
Large grains of feldspar*	—	—	X
Small grains of feldspar	X	—	—
Recrystallized carbonate	—	X	—
Fossil fragments	—	X	—
Major part of clastic carbonate	—	X	—
Minor part of clastic carbonate†	X	—	—
Chert	—	X	—
Clay	X	—	—
Accessories, divided proportionally	X	X	X

* Divided at grain size at 0.032 mm. (nominal sectional diameter).
† Up to 5–10 per cent of clastic carbonate.

TABLE 2.—*Calculation of microlithologies*

In per cent, Thorold siltstone, Genesee Gorge, Rochester, New York.

Mineral	Total Analysis (by weight)	Argillaceous Complementary Microlithology	Calcareous Complementary Microlithology	Siliceous Complementary Microlithology
Quartz	54.	6.	—	48.
Feldspar	1.	.1	—	.9
Recrystallized Calcite	5.	—	5.	—
Clastic calcite	10.	1.	9.	—
Clay	28.	28.	—	—
Accessories	2.	.8	.2	1.0
Totals	100.	35.9	14.2	49.9
Round figures		36.0	14.0	50.0

TABLE 3.—*Calculation of the distribution of quartz*

Thorold siltstone, Genesee Gorge, Rochester, New York.

Frequency-distribution curve of quartz	Unit	Area square inches	Per cent
On basis of quartz, 100 per cent	Total curve	3.20	100.0
	Argillaceous portion	.35	11.0
	Siliceous portion	2.85	89.0
On basis of quartz, actual per cent in rock	Quartz in rock		54.0
	Argillaceous portion		6.0
	Siliceous portion		48.0

Division point between argillaceous and siliceous portions: .032 mm. nominal sectional diameter.

The clastic carbonate was divided between the calcareous and the argillaceous microlithologies on the basis of a percentage governed by microscopic examination. The recrystallized calcite, on the other hand, because of the larger grain size and

greater angularity, is assigned to the calcareous microlithology. Clastic grains of carbonate readily recrystallize and become larger after deposition. This means that limy rocks that have experienced recrystallization are expressed by a different ratio of microlithologies. Certainly the rocks themselves have been changed in character.

The chart was assigned to the calcareous microlithology, as previously explained.

These concepts have resulted in the following "rules" which were used for calculating these microlithologies. A certain amount of artificiality cannot be eliminated, however. In this respect, criticism is not entirely unwarranted. *The quantitative classification of igneous rocks* of Washington, Iddings, Pirsson, and Cross has received some unfavorable comment, but its value has been considerable. Further study of sediments in thin sections will undoubtedly lead to improvements in calculating microlithologies.

RULES FOR CALCULATING MICROLITHOLOGIES

(1) All the clay minerals were assigned to the argillaceous microlithology.

(2) The frequency-distribution curves of the quartz grains were divided into two parts: the small grains were allocated to the argillaceous microlithology, the larger grains to the siliceous. The point along the size scale that bisected the curve was based upon grain measurements of highly fissile rocks which constitute the argillaceous end member of the argillaceous-siliceous binary system. The largest quartz grains of such rocks were .032 mm. in nominal sectional diameter. This value was statistically determined. It so happens that this value divides the author's metric grade scale (Alling, 1943, p. 259–269) at a convenient point: that between fine and medium siltstone. The areas of the two parts of the curve were measured by a polar planimeter. The ratio of these two areas was used to divide the percentage of the total quartz in the rock between the argillaceous and siliceous microlithologies.

(3) The feldspar content was allocated by the same method as the quartz, from frequency-distribution curves of either the feldspar (if measured) or the quartz. These are not always identical, but usually they are very close.

(4) The recrystallized carbonate and the fossil fragments were assigned to the calcareous microlithology.

(5) Five to 10 per cent of the clastic carbonate was allocated to the argillaceous microlithology, provided there is clay in the rock. The remaining amount of the clastic carbonate was assigned to the calcareous microlithology.

(6) The accessory minerals were divided among the three microlithologies in proportion to the relative amounts of each.

(7) Chert in limestones was assigned to the calcareous microlithology.

PLOTTING OF THE MICROLITHOLOGIES

Such calculated microlithologies of New York sediments, when plotted on a triangular base (Fig. 3 A), show that the dots are congested along two sides (argillaceous-siliceous, argillaceous-calcareous) but not along the base (calcareous-siliceous). Thus for most purposes these New York rocks can be regarded as binary systems (Fig. 3 B, C). The reduction of the ternary system to a pair of binaries

reduces areal diagrams to line figures, making it possible to show graphically an additional variable, such as grain size (Fig. 6 E). The per cent lithology of each sedimentary rock can be expressed in an analogous manner to that of the plagioclase

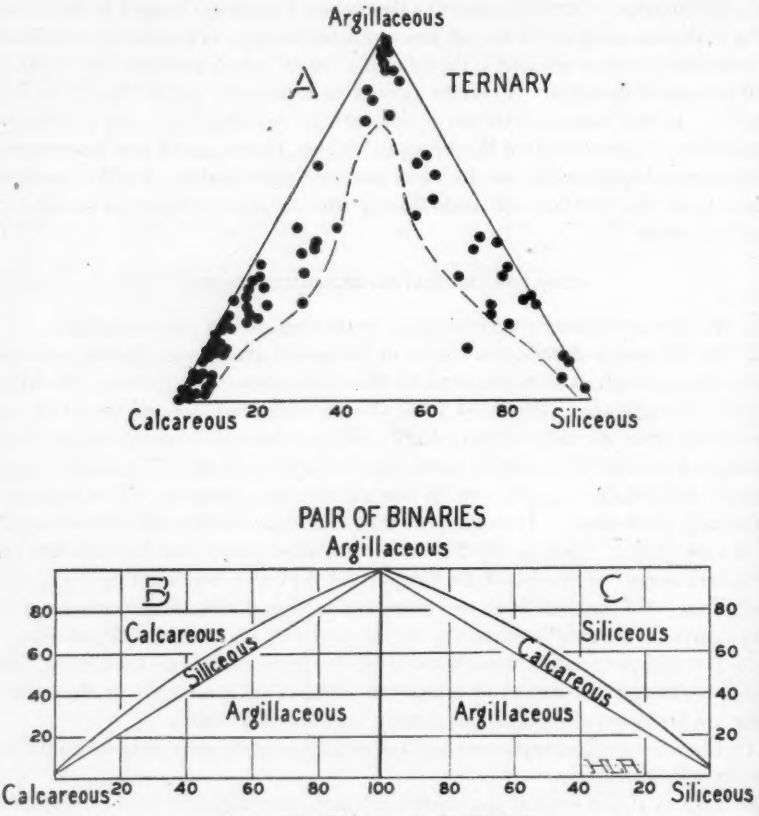

FIGURE 3.—*Diagrams of microlithologies*

A. Ternary diagram of microlithologies, showing basis for treating sediments as binaries.
B, C. Pair of binary diagrams, with the argillaceous microlithology in common. Most New York rocks fit into either one or the other of these diagrams. Used in plotting Figure 6E.

feldspars with similar symbols: A, argillaceous, C, calcareous, and S, siliceous, such as $A_{70}\ S_{30}$ and so on. Or, more precisely, they can be expressed as a three-component system, as $A_{70}\ C_5\ S_{25}$, for example.

USES OF MICROLITHOLOGIES

MICROLITHOLOGIES IN STRATIGRAPHY

Complementary microlithologies appear to provide a satisfactory method of plotting the lithology of sediments along geological columns or well logs. It is more

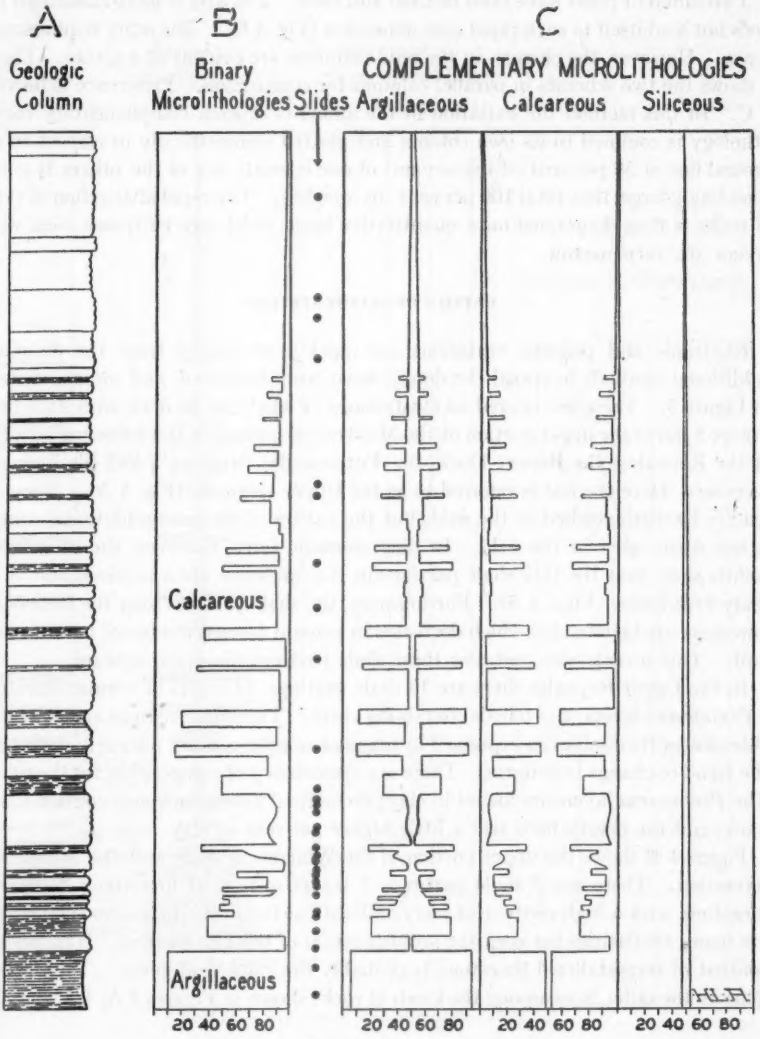

FIGURE 4.—*Geologic column of Figure 1 A*

With added microlithologies showing two methods of plotting.
B. Single column binary.
C. A ternary system in three columns.

precise than attempts to devise and draw a legend of patterns to express limy shales, calcareous sandstones, and other intermediate types (Fig. 1). Each specimen, therefore, provides data for either a pair or a trio of complementary microlithologies.

Two different plans have been devised and used. The first is more condensed but does not lend itself to such rapid comprehension (Fig. 4 B). The other requires more space. However, the changes in the sedimentation are evident at a glance. Figure 4 shows the two schemes in parallel columns for comparison. Preference is for plan 4 C. In this method the variation in the amounts of each complementary microlithology is confined to its own column and plotted symmetrically in respect to the central line of 50 per cent; if the amount of one is small, one of the others is correspondingly large; they total 100 per cent (by weight). The rapid alternation of types of rocks is thus diagramed on a quantitative basis which can be shown even when layers are very narrow.

DETAILS OF SEDIMENTATION

Rhythmic and periodic variations are quickly recognized from the diagrams. Additional methods to reveal the details have been developed, and some are shown in Figure 5. These are offered as illustrations of what can be done with such data. Figure 5 shows the upper portion of the Maplewood formation and following members of the Reynales: the Brewer Dock, the Furnaceville "iron ore", and the limestone member. Here the last is referred to as the Upper Reynales (Fig. 1 A). They can readily be distinguished in the field, but the nature of the intergradational contact is not easily seen in the field. In diagrammatic form, however, the microscopic results show that the thin shale partings in the limestone are a continuation of the shaly beds below (Figs. 4, 5). Furthermore, the shale partings near the base of the limestone are high in clay which decreases in amount toward the top of the limestone unit. This reveals why and how these shale partings disappear upward.

In the Upper Reynales there are 13 shale partings, 14 layers of normal limestone, 6 *Pentamerus* layers, and 6 beds containing chert. The shale partings are quite variable among themselves as expressed in terms of complementary microlithologies, but the trend of change is uniform. There is a consistency of composition for the others. The *Pentamerus* layers are lowest in clay; the normal limestone layers contain a little more, and the cherty beds still a little higher per cent of clay.

Figure 1 B shows the upper portion of the Williamson shale and the Irondequoit formation. There are 9 shale partings, 8 layers of normal limestone, 2 layers of limestone with a high content of recrystallized calcite, and a bryozoan reef. There are many similarities between the sedimentation of the two sections. The low clay content of recrystallized limestone is probably the cause and effect. Table 4 summarizes the differences among the kinds of rocks shown in Figures 1 A, 4 A, and 5 A.

MICROPHASES

Petrographic examination of the Maplewood shale and of the shale partings in the Brewer Dock and Upper Reynales reveals the identical kind and character of the clay of all three stratigraphic units. A phase in this case is a mineral, the presence of which is characteristic of a vertical range of sediments, which has been found to be diagnostic. A useful microphase is analogous to a diagnostic index fossil. This

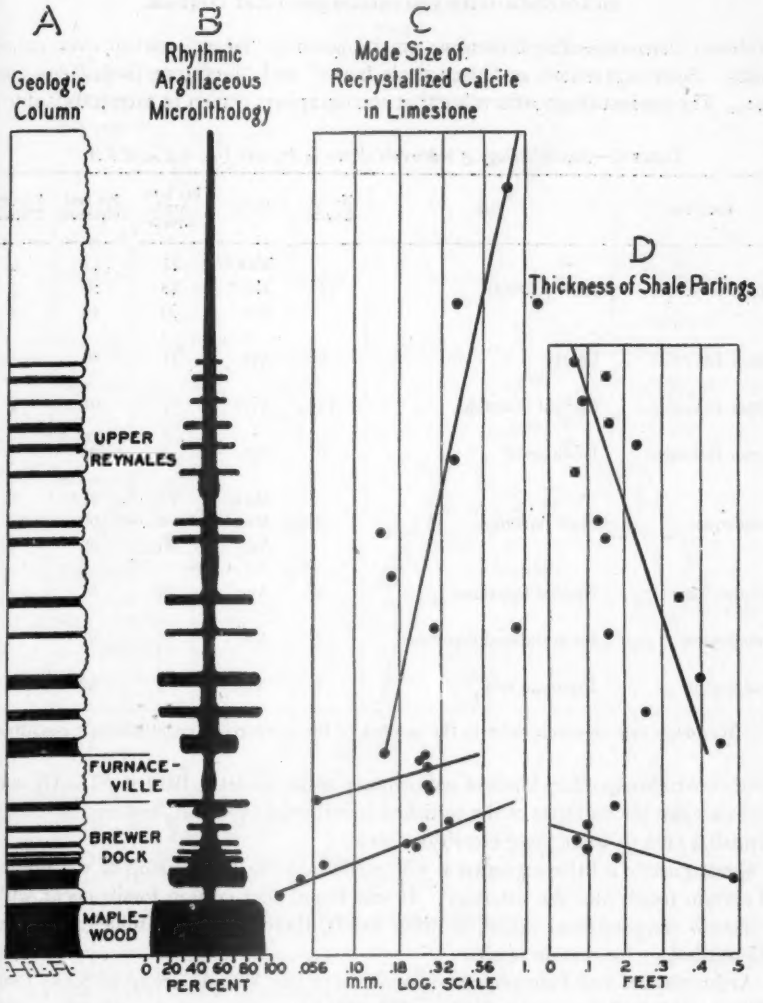

FIGURE 5.—*Diagrams of sedimentation details*

A. The same geologic column of Figures 1A and 4A showing:
B. Cyclic rhythms in terms of the argillaceous microlithology
C. Mode size of the recrystallized calcite in limestone
D. Plot of the thickness of the shale partings
Note in column B how the pattern of the Brewer Dock is a condensed version of the Upper Reynales.

particular microphase has been called the Maplewood clay microphase (Alling, 1945). This concept has proved useful in recognizing the vertical intergradation of certain microphases across formational boundaries.

MICROLITHOLOGIES AND PALEONTOLOGICAL CONTROL

General statement.—Paleontologists are recognizing "facies" control over certain fossils. Such expressions as "black shale fauna" and "limestone fossils" are common. The present diagnostic value that stratigraphers attach to ostracods is due to

TABLE 4.—*Microlithology of sediments shown in Figures 1 A, 4 A, and 5 A*

Rock Unit	Beds	No. of Layers	Value	Per cent Argillaceous	Per cent Calcareous	Per cent Siliceous
Upper Reynales....	Shale partings	13	Max.*	81	13	6
			Min.*	18	80	2
			Ave.	50	46	4
Upper Reynales....	Cherty	6	Ave.	11	86	3
Upper Reynales....	Normal limestone	14	Ave.	7	91	2
Upper Reynales....	Pentamerus	6	Ave.	5	93	2
Irondequoit.....	Shale partings	9	Max.*	77	17	6
			Min.*	6	90	4
			Ave.	36	59	5
Irondequoit.....	Normal limestone	8	Ave.	10	87	3
Irondequoit.....	Recrystallized limestone	2	Ave.	4	95	1
Irondequoit.....	Bryozoan reef	1	Ave.	1	98	1

* Maximum and minimum refer to the amount of the argillaceous microlithologic constituent.

their occurrence in many kinds of sedimentary rocks (Gillette, 1940, p. 52). Of course rocks are not photographs of the vanished conditions of the past, but microlithologies furnish a clue to what these conditions were.

Consequently a little exploration was made into the relationship of the presence of certain fossils and the lithology. It was found that certain fossils occur within a narrow compositional range; in other words, there is a paleontological preferred microlithology for certain fossils.

Arthrophycus *and* Paleophycus.—Students of the Medina group of rocks (Sarle, 1901, p. 203–210; Schuchert, 1914, p. 277–320) have expressed the belief that *Paleophycus tortuosum* is confined to certain layers of the Queenston formation, and *Arthrophycus alleghaniensis* is limited to the Grimsby and Thorold. Study of the microlithologies shows that the rocks differ in composition in most cases. *Paleophycus* occurs in a rock ranging from $A_{55}C_{15}S_{30}$ to $A_{98}C_1S_1$, an argillaceous-rich rock with a structure ranging from thin-bedded to fissile, while *Arthrophycus* occurs in a more siliceous rock ranging from $A_{58}C_1S_{41}$ to $A_0C_{10}S_{90}$, massive to thin-bedded siltstones to sandstones (Fig. 6 A).

In general the Queenston and Grimsby correspond to these ranges in composition,

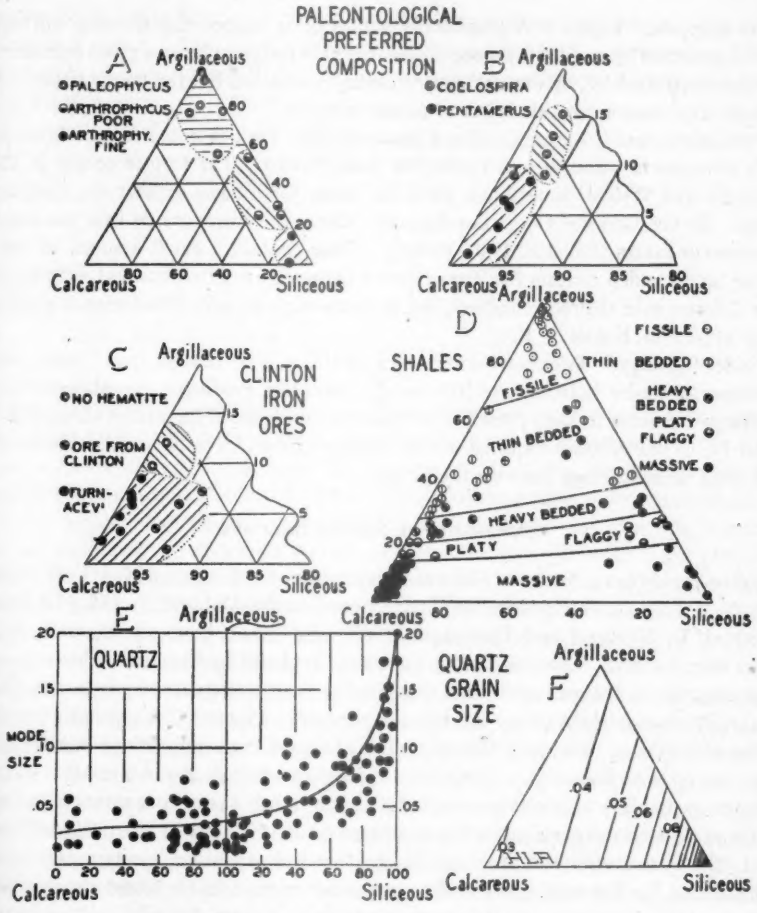

FIGURE 6.—*Binary and ternary diagrams*

A. and B. Paleontological preferred microlithology.
A. *Arthrophycus* and *Paleophycus* from the Grimsby and Queenston, mostly from the Genesee Gorge.
B. *Pentamerus* and *Coelospira* from the Reynales formation, Genesee Gorge.
C. Composition of Clinton iron ores recalculated as limestone, Western and Central New York. Nine per cent or more argillaceous microlithology precludes replacement by iron.
D. The relationship of the microlithology of sediments to shaliness and ease of splitting.
E. and F. Relationship of microlithologies of sediments and the mode grain size of quartz.
F. As binaries.
G. As a ternary. Graphic average plotted by contours. Quartz sizes as modes.

but the finding of a specimen of *Paleophycus* in a red shale near the top of the Grimsby at Cuylerville, New York, with a high argillaceous content, shows that the composition is favorable for *Paleophycus*. The environment that resulted in the particular composition of these rocks controlled the presence of the organisms that made these

worm burrows. Figure 6 A graphically shows these ranges and the type of rock that is preferred by each of these organisms; they are not peculiar to a given formation but are controlled by, or were at least profoundly affected by, the composition. A biologic explanation for this is left to paleontologists.

Pentamerus *and* Coelospira.—The Clinton of New York is noted for the brachiopods *Pentamerus oblongus* and *Coelospira hemispherica*. The former occurs in the Reynales and Wolcott limestones, while the latter fossil has a greater stratigraphic range. In the Genesee Gorge the Reynales above the Furnaceville iron ore has 6 *Pentamerus* layers (Gillette, 1940, p. 49). These contain a small amount of clay. Those layers which contain *Coelospira* have a little more argillaceous matter in them. The differences in the rock compositions, in terms of three microlithologies, is graphically shown in Figure 6 B.

Under "ecology," Twenhofel and Shrock (1935, p. 297) remark that "Some, like *Pentamerus*, desire bottoms free from mud, others like *Productus*, *Strophomena*, and *Refinesquina*, seem to have preferred bottoms receiving small quantities of mud; and other forms like *Lingula* required muddy bottoms in which to burrow." Evidently here also microlithology controls the fauna.

COMPOSITION OF CLINTON IRON ORE

Petrographic examination of slides of iron ore from the Clinton of New York State, including those at the type locality (Dale), reveal, as Smyth (1892, p. 487–492; 1894, p. 304–313), Newland and Hartnagel (1908), and others have shown, that these rocks were formerly limestones which have been replaced by hematite. Microlithologic analyses of the ores show that these limestones were replaced by iron, provided the argillaceous microlithology was below 9 per cent. Figure 6 C is a graphic presentation of the data. The gray "Furnaceville" at Glen Edyth (east side of Irondequoit Bay) contains no hematite. There were at least two factors in the formation of the ore: the availability of iron solutions, and limestones with a low clay content occurring at the same time and place under the same conditions. Gillette (1940, p. 49) believed that "the Furnaceville is a lithologic designation and carries no [stratigraphic] time connotation." The uniformity of the composition of replaceable limestones horizontally may not be great. Consequently, these iron ores are regarded as long lenses.

In calculating the composition of these ores, the hematite, as measured by the Wentworth stage, was recalculated as carbonate for the purpose of comparing the ores with the nonhematite-bearing limestones. The results of this study show that if the limestone were to be replaced by iron solutions, the clay content of the limestones had to be low.

The Clinton ores are replacement deposits, but not in the usual sense of the economic geologist. Bateman (1943, p. 567–569) speaks of them as "straight" sedimentary rocks. He did not desire, of course, to imply that hematite may be found above or below the sedimentary beds that constitute the ore. The replacement was part of the processes of the formation of the rock. The replacement evidently took place after deposition. Some permeability of the rock for the migration of the iron solutions seems perhaps necessary. Reduction of this would render the limestones less

susceptible to replacement. A high clay content probably would reduce the permeability of the rock. Perhaps this is an explanation of the preferred microlithological range of the Clinton ores. This may not be the sole reason, but it is regarded as an important factor.

TABLE 5.—*Ease of splitting and kind of shale*

Ease of Splitting	Term
Very hard	Massive
Hard	Platy—Flaggy
Intermediate	Heavy-bedded
Easy	Thin-bedded
Very easy	Fissile

SHALES

Examination of the microlithologic analyses of "shales" and petrofabric diagrams of the quartz and the mica of shaly rocks has convinced the author that the term shale is essentially a structural one (Wentworth, 1922, p. 387), depending upon the foliation, bedding, and orientation of the constituents and their minute grain sizes, so the rock splits or can be split parallel to the bedding. The clay minerals, oriented parallel to this plane, contribute to this property, but their presence is not the only cause and perhaps not the chief cause of this structure. "Shale" is perhaps a satisfactory term for use in the field, but it is too general and crude to be commensurate with the precision of microscopic analysis. The relationship between the ability of a rock to split and its composition needs quantitative definition.

Shales range from those with obscure foliation, massive in character, to those highly fissile. Consequently the current expressions massive, platy, flaggy, heavy-bedded, thin-bedded, and fissile were studied with the purpose of giving them quantitative values. These were checked by designing and constructing a device along the pattern of the strength-testing machines of county fairs. The blows of a hammer could thus be measured. Using a chisel on hand specimens, some quantitative measurements of the ease of splitting were obtained. It was found that, to secure relatively consistent results, fresh pieces were necessary. There is much that can be done in this field of investigation.

Rocks were thereby classified (Table 5):

The shaliness of sediments in terms of microlithologies shows an approximate relationship. "Contours" of the ease of splitting have been drawn across the triangle of Figure 6 D. Excluding massive and platy-flaggy rocks as non shales, the remainder constitutes 51 per cent of the whole. "Shale" is consequently too broad a term (literally) to be quantitatively useful. As an adjective, referring to the structure, the word "shaly" has significance. The lithology of rocks, on the other hand, can be expressed quantitatively in terms of the three microlithologies.

GRAIN SIZES AND MICROLITHOLOGIES

On plotting the lithologic composition of the New York State sediments in terms of the microlithologies in pairs against the mode size of the quartz, it was found that the

size increases with the increase in the siliceous microlithology (Figs. 6 E, 6 F). Preliminary studies of limestones show that those low in clay usually contain more recrystallized calcite, and the grain sizes of the calcite are larger.

SUMMARY

(1) Thin sections of consolidated sedimentary rocks were analyzed as follows: The mineralogical composition by weight per cent was determined microscopically by the Delésse-Rosiwal method of intercepts by a Wentworth stage. Grain size of the quartz and carbonates was measured in two dimensions.

(2) The mineralogical composition of the rocks was calculated into the terms of two or three complementary microlithologies, which serve as "end members." The methods and "rules" for these calculations are given. This is analogous to calculating norms of igneous rocks from chemical analyses.

(3) The complementary microlithologies were plotted against geologic columns.

(4) These diagrams reveal the make-up of each layer. Rhythmic and periodic variations in the sedimentation are thereby quickly recognized.

(5) Microlithologic analysis of some of the fossil-bearing rocks in the collection shows that certain fossils occur only in narrow microlithologic ranges. "Facies" control is thus put upon a quantitative basis.

(6) The Clinton iron ores of New York were believed to be originally limestones, which were replaced, during diagenesis, by iron from solutions presumably derived from lateritic sources. Microlithologic analyses of the beds show that such limestones were replaceable provided the iron solutions were available and the limestones contained less than 9 per cent of the argillaceous microlithology. It is believed that a high argillaceous content reduced the permeability so the iron solutions could not enter. The writer agrees with Gillette that these Clinton ores possess no stratigraphic connotations; they are lithologic designations only.

(7) Some of the factors that produce shaly rocks were measured and plotted on a triangular base in terms of three microlithologies (Fig. 6 D). The term "shale" is too broad to be more than a field expression. It is essentially structural in implication, rather than compositional. The orientation, the minute grain size, and the pronounced cleavage of some of the constituents are all factors; composition alone is not the chief cause of shaly rocks (Fig. 6 D).

(8) The size of quartz grains (mode) of these New York sediments increases with increasing amount of the siliceous microlithology. Likewise the amount and grain size of recrystallized calcite in limestones increases with decrease in the amount of the argillaceous microlithology.

(9) The suggestion is made that paleontologists pay more attention to the lithologies of the rocks from which fossils are collected and report the exact horizons. Then we will possess more reliable data regarding the environment. Sarle's (1901, p. 203–210) and Schuchert's (1914, p. 270–320) records of the occurrence of *Arthrophycus* and *Daedalus* in the Grimsby of the Medina in the Genesee Gorge at Rochester are to be commended.

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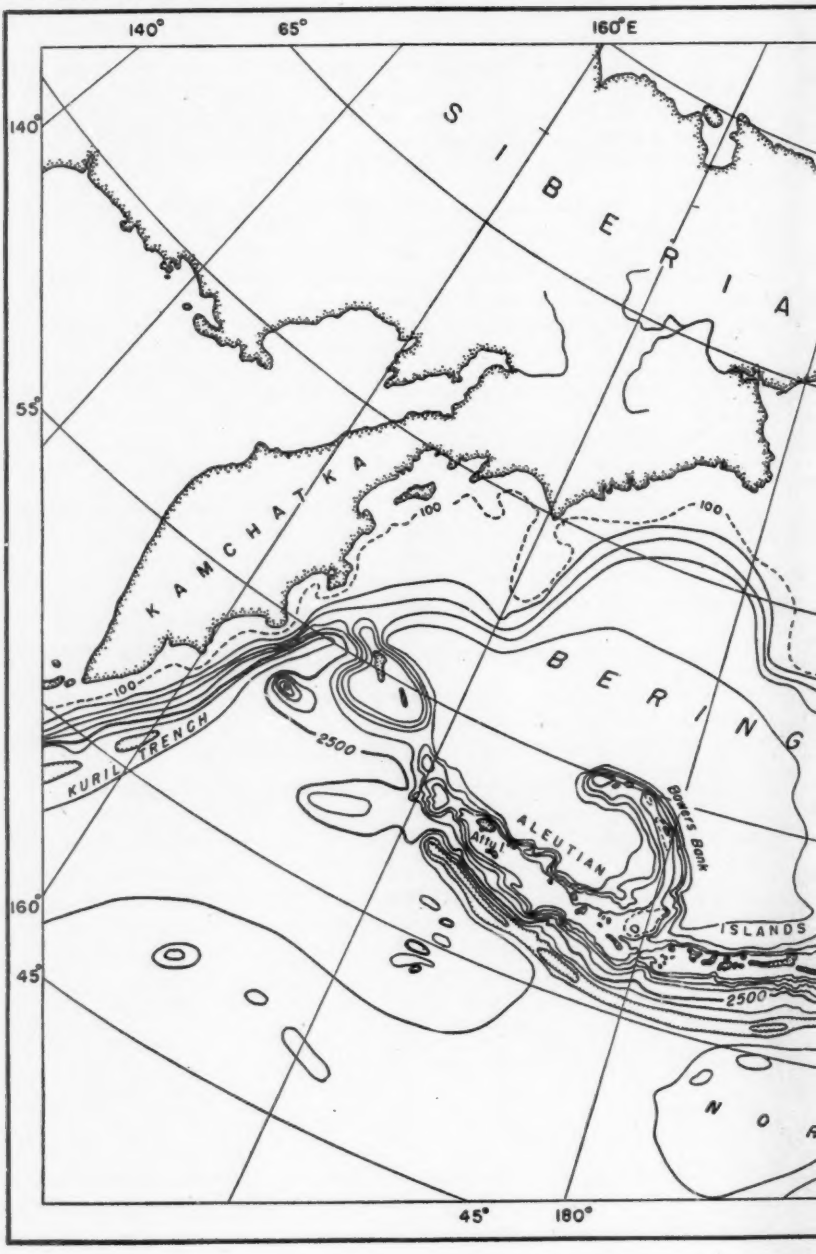
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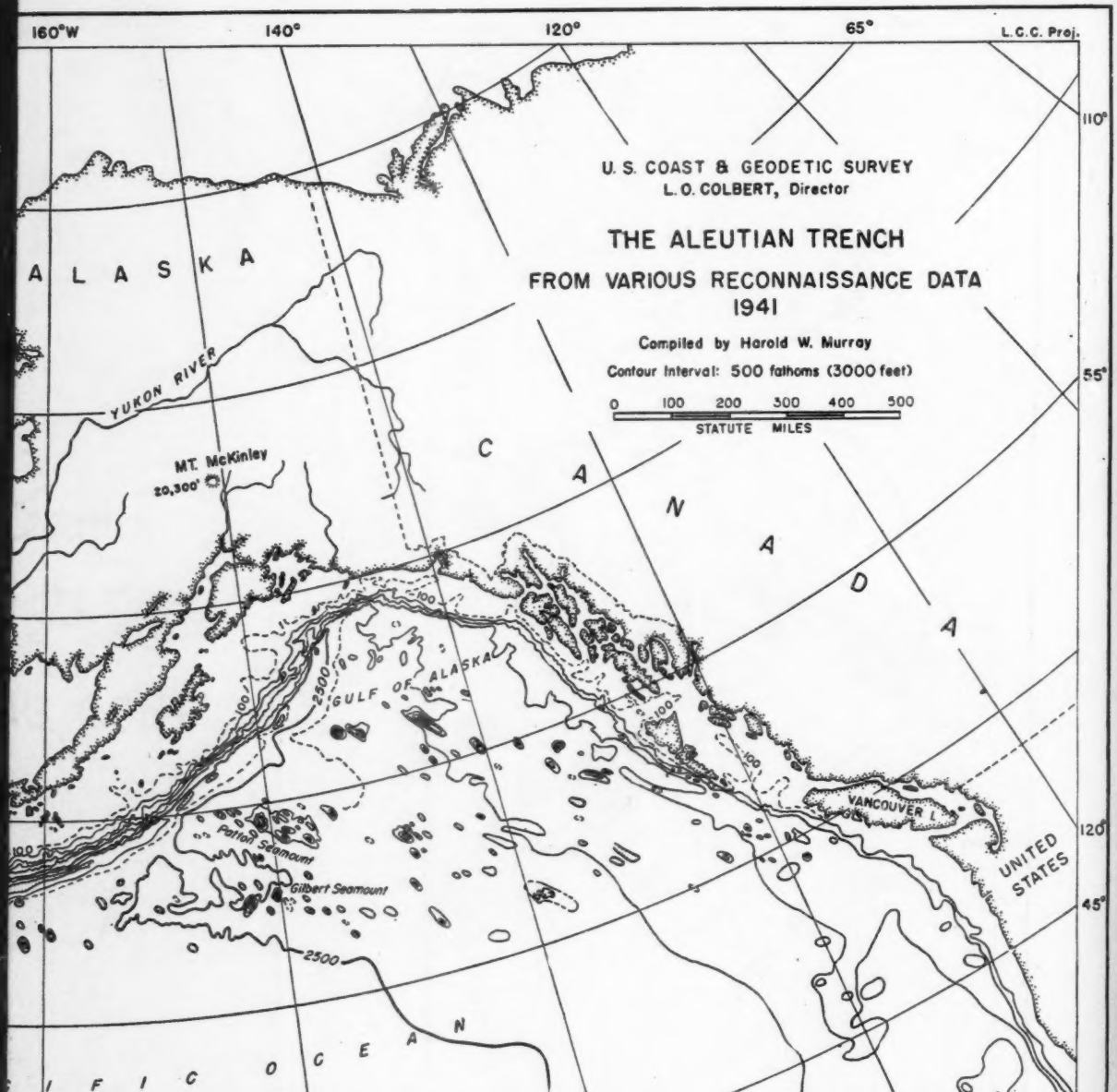

UTIAN TRENCH

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PROFILES OF THE ALEUTIAN TRENCH

BY HAROLD W. MURRAY

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ABSTRACT

This paper is a sequel to *Submarine mountains in the Gulf of Alaska* (Murray, 1941) and concludes presentation of the U. S. Coast and Geodetic Survey's sounding data across the Gulf of Alaska and the eastern half of the Aleutian Trench.

The writer presents 6200 statute miles of profiles constructed from 45 sounding lines across the trench and from several lines paralleling the continental slope. The locations of all soundings used in the construction of the profiles (about 7000) are indicated. Accompanying contour maps are based on all available data.

The Aleutian Trench is about 2200 statute miles long, 50 to 100 miles wide, and has a maximum depth of slightly over 25,000 feet. The north side of the trench slopes 3°–4° and the south side 1°–4°. Locally, however, the slopes exceed 30°. Submarine valleys indent the north slope and extend out to depths of 9000 to 12,000 feet. The maximum difference between the floor of the trench and the adjacent land features is about 32,000 feet. The locus of maximum relief is located midway along the arc of the trench.

The salient features of the submarine topography which must be considered in any investigation of the evolution of this region are: (1) The trench and the Aleutian Islands conform to the arc of a circle for 1400 miles. (2) The deeper part of the trench is in the western half. (3) In the Gulf of Alaska, numerous submarine mountains stand as high as 12,000 feet above the ocean floor. They occur singly or in groups, have truncated or rounded tops, and trend northwestward. This direction is transverse to that of the trench and suggests at least two episodes in the evolution of relief in the Gulf region alone. (4) The floors of the Gulf of Alaska and Bering Sea slope southwestward. (5) A curving submarine range, 12,000 feet high and 600 miles long, projects from the Aleutian arc into the Bering Sea.

INTRODUCTION

Although the existence of the elongate depressions in the Pacific Ocean, including the Mindanao Trench with its record depth of 5900 fathoms or 35,400 feet, has been known for many years, their detailed characteristics are little known. An appreciation of these details, however, is essential to a more complete understanding of the origins of these features. This is especially true of the Aleutian Trench concerning which published sounding data have been extremely meager.

Because of the extent of these oceanic deeps and the attendant difficulties and expense of sounding, adequate information can be acquired only piecemeal. In the present report, results of the explorations of the U. S. Coast and Geodetic Survey in the eastern portion of the Aleutian Trench during the period from 1925 to 1940 are presented in both profiles and contours.

GENERAL CONSIDERATIONS

The Aleutian Trench or foredeep is a narrow elongate depression in the ocean floor paralleling the convex, south side of the Kenai and Alaska peninsulas and the Aleu-

tian archipelago in the North Pacific Ocean. Extending from Yakutat Bay in the Gulf of Alaska westward to Attu Island at the end of the Aleutian Islands, this remarkable trench is over 2200 statute miles long and has a maximum depth of over 25,000 feet.

FIGURE 1.—*Graphic relation of Aleutian Islands to arc of a circle*

The peninsulas, islands, and foredeep are arcuate. The Aleutian Islands alone form an arc of a circle (Fig. 1) having a radius of about 760 statute miles; the length along the arc is over 1400 miles. These distances were measured on a 30-inch globe. The origin of the circle is centered in about Lat. 62° 40′ N., Long. 178° 20′ W.

The conspicuous features of the Aleutian Islands and part of the peninsulas just north of the trench are primarily volcanic. The islands, rising from maximum depths of about 14,000 feet in the Bering Sea or 25,000 feet from the bottom of the trench on the south, are actually the summits of mountains which in turn protrude several thousand feet (Fig. 12) above the surface of the ocean.

SOUNDING DATA AND METHODS OF PRESENTATION

DEEP SEA HYDROGRAPHY

Echo-sounding lines across the Gulf of Alaska and westward to the Islands of Four Mountains were begun by the U. S. Coast and Geodetic Survey in 1925 (Pl. 2). At the close of the 1940 season, over 58 sounding lines spaced at average intervals of 15 miles were run across the trench. Over 40,000 echo soundings, corrected for temperature and salinity, were obtained in this region. This deep-sea work is of a reconnaissance nature economically carried out by the Bureau's vessels enroute to and from their Alaskan working grounds. The astronomic and dead-reckoning control of these lines is not comparable with the Bureau's more rigid taut-wire control used in off-shore coastal surveys as described by Borden (1938). However, a single sounding line may be controlled by as many as 100 astronomic sights. With thoroughly favorable weather, the theoretical accuracy of astronomic positions is probably within 1 to 2 miles. Ideal observing conditions, however, were not always possible for each single sight, nor in some cases for most of an entire sounding line.

Practically all soundings were obtained with the Coast and Geodetic Survey's Submarine Signal Type 312 Fathometer calibrated for standard velocities of either 800 or 820 fathoms per second. The manner of recording soundings, the nature of corrections, and the influence of direction in which lines approach and cross significant features in this region have been previously considered (Murray, 1941) and need not be repeated. It seems advisable, however, to emphasize certain considerations. Since echoes are usually received from the nearest suitable configuration, in areas of sloping or irregular relief the echo is rarely returned from beneath the sounding vessel. In the case of the profiles shown herein, it will be noted from Plate 2 that economical coverage to the working grounds has been achieved by running most of the sounding lines diagonally across the trench. Most profile illustrations are therefore actually transverse profiles. Consequently, echoes on the continental slope, as for example, in Group III (Fig. 4), are usually reflected from areas slightly northward. Conversely, when the outer seaward slope is crossed, the echoes are reflected from areas slightly southward. Because of the great depths and slopes, present supersonic equipment will probably not, at least for some years to come, entirely overcome the foregoing characteristics. Velocity corrections for depths as great as 4200 fathoms (25,200 feet) encountered in this region are appreciable, particularly when an instrumental calibration of 800 fathoms (4800 feet) per second is used. In the instance cited, these corrections amount to about 190 fathoms (1140 feet). Hence, care must be exercised in evaluating soundings.

Deep-sea sounding information throughout most of the westerly Aleutian Island region is scarce. The available data have been contributed mainly by vessels of the U. S. Coast and Geodetic Survey, the U. S. Navy, the U. S. Coast Guard, and the Fish Commission's ALBATROSS. Copies of sources of most of this material are on file in the Bureau's archives. The more important available published data in the Bureau's archives are listed under References cited.

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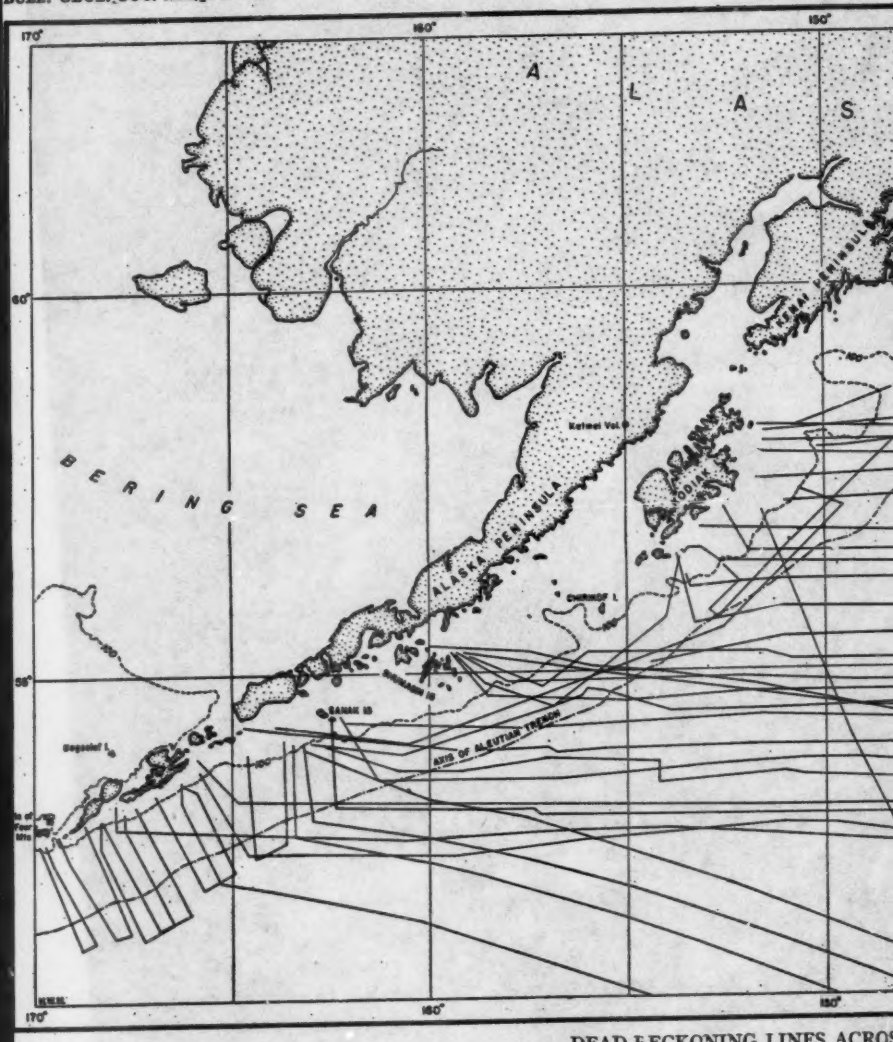

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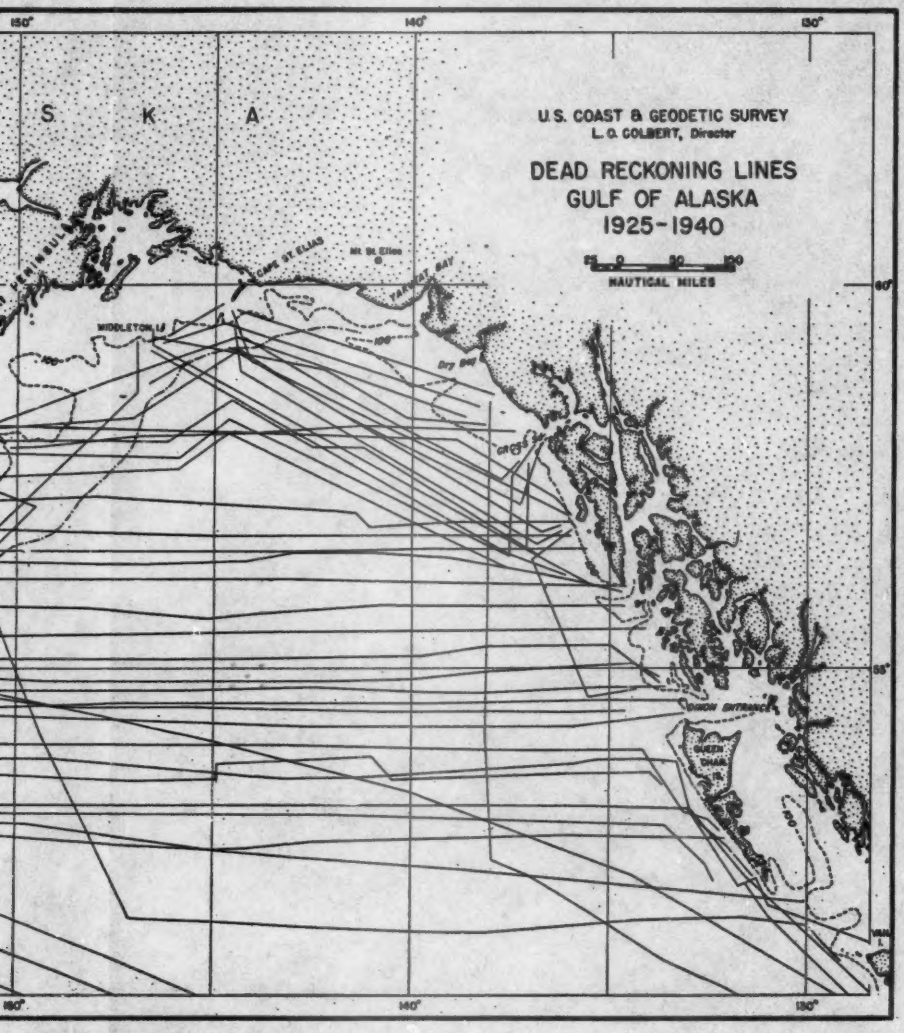

S ACROSS THE GULF OF ALASKA

CONTINENTAL-SHELF HYDROGRAPHY

The continental shelf fronting the north side of the trench between Cape St. Elias and the southern end of Kodiak Island, and from Sanak Island to Seguam Island (Long. 172° 25′ W.) has been surveyed out to the 100-fathom curve by the Coast and Geodetic Survey. In the smaller intervening areas, hydrographic information is incomplete, and some of it is of a reconnaissance nature. Part of the latter information is of Russian origin prior to 1867 when the Territory of Alaska was purchased.

CONTOURS OR SKETCH LINES

The 500-fathom contours in Plates 1 and 2 are in general based on reconnaissance data. However, the vicinities of Unalaska, Bogoslof, and Umnak islands, and the Islands of Four Mountains were contoured directly from recent surveys of the Coast and Geodetic Survey on scales of from 1 to 80,000 to 1 to 160,000. The outer limit of these surveys just south of these islands is between the 1500- and 2000-fathom contours. The northern limit on the Bering Sea side is a line extending westward from the southern tip of Unimak Island. The broken contours north of this line were sketched from widely scattered soundings of miscellaneous origin but particularly from cruises of the Fish Commission's ALBATROSS (1883–1906).

The region of Bogoslof Island, the most interesting active volcano of the Aleutians, was earlier contoured with a 25-fathom interval by Smith (1937). His contour map extends about 55 miles northeast of the island and 25 miles southwestward. It covers an area of over 3000 square statute miles and portrays the relief in this area in greater detail than is warranted in the present article.

MAP PROJECTIONS

Deep-sea track lines are usually plotted on special Mercator Plotting Sheets issued by the U. S. Hydrographic Office. The writer, for his own convenience, has used the Mercator projection in Plates 2 and 3 and in Figure 14. The entire Aleutian Trench as shown in Plate 1, however, has been compiled on the Bureau's Aeronautical Chart No. 3069a. This chart (color tinted) is constructed on the Lambert Conformal Conic projection with standard parallels of strength at latitudes 55° and 65°.

PROFILES OF TRENCH

Chronology data.—Analysis of the numerous Coast and Geodetic Survey soundings across the Aleutian Trench reveals a wealth of information which cannot adequately be represented in contour maps such as Plates 1 and 3. Therefore, selected profiles (Figs. 2–10) of the sounding lines on Plate 2 have been prepared to bring out this additional information.

Forty-five sounding-line profiles, arranged in consecutive order from Yakutat Bay to the Islands of Four Mountains, are presented in groups (Figs. 2–9). The successive profiles in each group are, in general, aligned on a common axis which is based

TABLE 1.—*Chronology data of Coast and Geodetic Survey profiles and cross lines across the Gulf of Alaska and the Aleutian Trench*

PROFILE LINES ACROSS THE ALEUTIAN TRENCH

	Profile No.	Year	Vessel	Commanding Officer	General Course	Depth in Trench	Diff. (Fms.)
Group I	1	1934	SURVEYOR	Comdr. A. M. Sobieralski	Northwest	948	
	2	1936	DISCOVERER	Comdr. Jack Senior	Northwest	2080	−1132
	3	1932	SURVEYOR	Capt. F. B. T. Siems Comdr. A. M. Sobieralski	Northwest	2180	−100
	4	1937	DISCOVERER	Comdr. R. L. Schoppe	Northwest	2200	−20
	5	1928	SURVEYOR	Comdr. R. R. Lukens	Southeast	2287	−87
	6	1933	SURVEYOR	Capt. F. B. T. Siems Comdr. A. M. Sobieralski	Northwest	2225	+62
Group II	7	1938	DISCOVERER	Comdr. R. L. Schoppe	Northwest	2415	−190
	8	1935	SURVEYOR	Comdr. A. M. Sobieralski	Northwest	2455	−40
	9	1933	SURVEYOR	Comdr. A. M. Sobieralski	Southeast	2490	−35
	10	1932	DISCOVERER	Comdr. H. B. Campbell	Southwest	2650	−160
	11	1936	SURVEYOR	Comdr. A. M. Sobieralski	West	2622	+28
	12	1933	DISCOVERER	Comdr. H. B. Campbell	West	2720	−98
Group III	13	1934	DISCOVERER	Comdr. H. B. Campbell	West	2681	+39
	14	1935	DISCOVERER	Comdr. H. B. Campbell	West	2736	−55
	15	1938	PIONEER	Lt. Comdr. R. D. Horne	West	2750	−14
	16	1938	SURVEYOR	Comdr. A. M. Sobieralski	West	3085	−335
	17	1939	DISCOVERER	Lt. Comdr. G. C. Jones	West	2790	+295
Group IV	18	1939	SURVEYOR	Comdr. R. L. Schoppe	West	2975	−185
	19	1939	PIONEER	Lt. Comdr. R. D. Horne	West	2930	+45
	20	1937	SURVEYOR	Comdr. A. M. Sobieralski	West and North	2983	−53
	21	1939	GUIDE	Lt. Comdr. E. W. Eickelberg	West	3016	−33
	22	1925	PIONEER	Capt. R. F. Luce	East	2917	+99

Group V	23	1938	DISCOVERER	Comdr. R. L. Schoppe	East	3055	−138
	24	1936	SURVEYOR	Comdr. A. M. Sobieralski	East	3070	−15
	25	1935	DISCOVERER	Comdr. H. B. Campbell	East	3105	−35
	26	1935	SURVEYOR	Comdr. A. M. Sobieralski	East	3060	+45
	27	1936	DISCOVERER	Comdr. Jack Senior	East	3240	−180
	28	1937	SURVEYOR	Comdr. A. M. Sobieralski	East	3552	−312
Group VI	29	1937	DISCOVERER	Comdr. R. L. Schoppe	Southeast and West	3750	−198
	30	1939	DISCOVERER	Lt. Comdr. G. C. Jones	South and West	3795	−45
	31	1939	GUIDE	Lt. Comdr. E. W. Eickelberg	South and Southeast	3930	−135
	32	1937	DISCOVERER	Comdr. R. L. Schoppe	North	3875	+55
	33	1937	DISCOVERER	Comdr. R. L. Schoppe	South	3880	−5
Group VII	34	1939	SURVEYOR	Comdr. R. L. Schoppe	Southeast	3965	−85
	35	1937	SURVEYOR	Comdr. A. M. Sobieralski	Northwest	3944	+21
	36	1939	PIONEER	Lt. Comdr. R. D. Horne	Southeast	3929	+15
	37	1937	SURVEYOR	Comdr. A. M. Sobieralski	Southeast	392"	+2
	38	1939	SURVEYOR	Comdr. R. L. Schoppe	Northwest	3975	−48
	39	1936	SURVEYOR	Comdr. A. M. Sobieralski	Northwest	3933	+42
Group VIII	40	1939	SURVEYOR	Comdr. R. L. Schoppe	Southeast	3880	+53
	41	1936	SURVEYOR	Comdr. A. M. Sobieralski	Southeast	3950	−70
	42	1939	PIONEER	Lt. Comdr. R. D. Horne	Northwest	4030	−80
	43	1939	PIONEER	Lt. Comdr. R. D. Horne	Southeast	3987	+43
	44	1939	PIONEER	Lt. Comdr. R. D. Horne	Southeast	3987	0
	45	1939	PIONEER	Lt. Comdr. R. D. Horne	Northwest	3977	+10

TABLE 1.—*Continued.*

PROFILES ALONG THE CONTINENTAL SLOPE

	Profile No.	Year	Vessel	Commanding Officer	General Course	Depth in Trench
Group IX	A	1935	DISCOVERER	Comdr. H. B. Campbell	East	—
	B	1935	DISCOVERER	Comdr. H. B. Campbell	East	—
		1935	SURVEYOR	Comdr. A. M. Sobieralski	West	—
		1935	DISCOVERER	Comdr. H. B. Campbell	West	—
	C	1935	DISCOVERER	Comdr. H. B. Campbell	West	3015
	D	1935	DISCOVERER	Comdr. H. B. Campbell	West	2926
	E	1933	SURVEYOR	Capt. F. B. T. Siems	West	—
	F	1933	SURVEYOR	Comdr. A. M. Sobieralski	West	—

CROSS LINES ACROSS THE GULF OF ALASKA

Locality	Year	Vessel	Commanding Officer	General Course	Depth in Trench
Off Dry Bay	1940	SURVEYOR	Lt. Comdr. R. W. Knox	South	—
Off Kodiak I.	1940	DISCOVERER	Lt. Comdr. L. D. Graham	Southeast	2970 fathoms

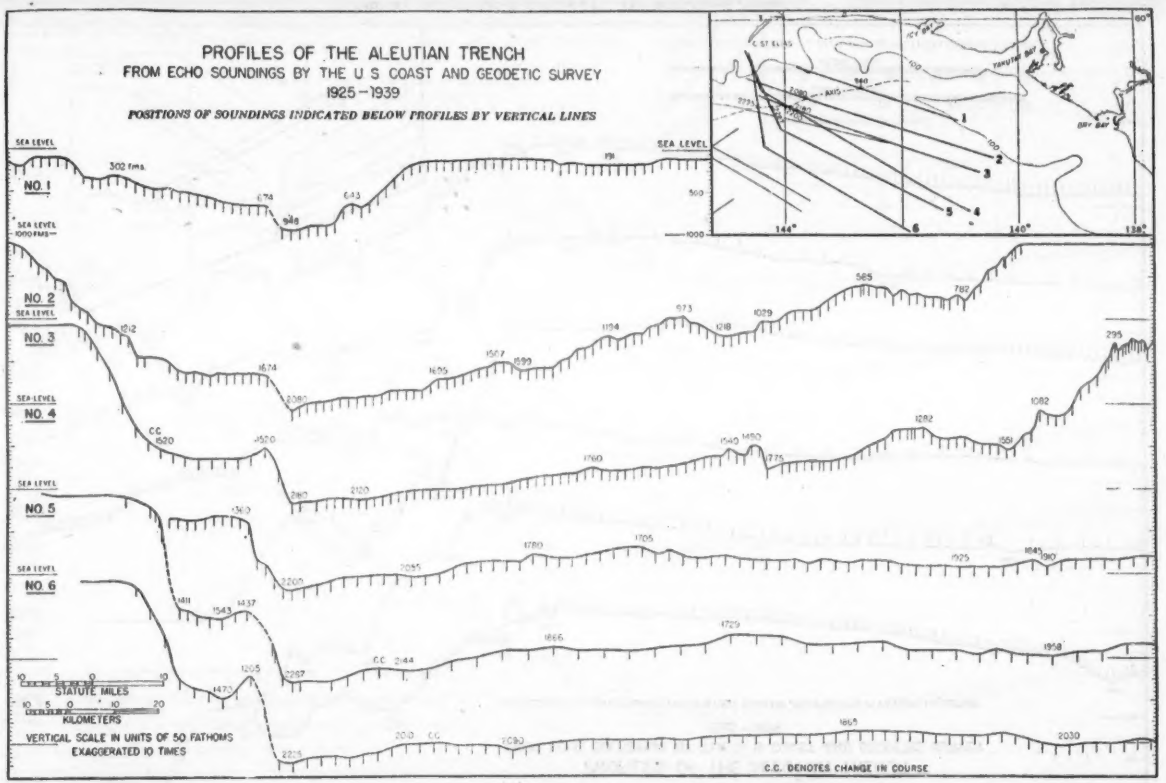

FIGURE 2.—*Profiles, Group I. Cape St. Elias to Yakutat Bay*

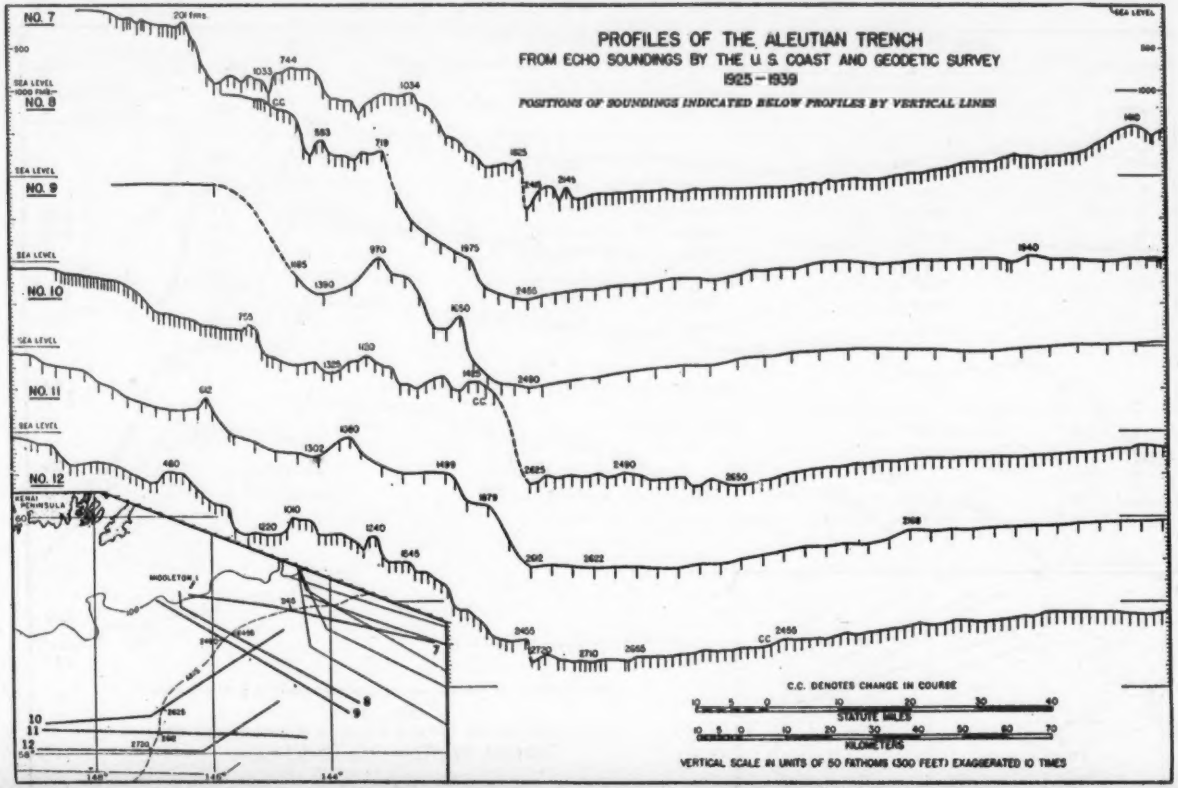

FIGURE 3.—*Profiles, Group II. Off Middleton Island*

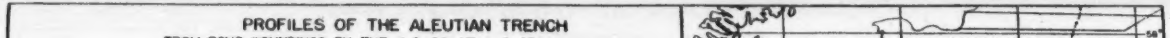

FIGURE 3.—*Profiles, Group II. Off Middleton Island*

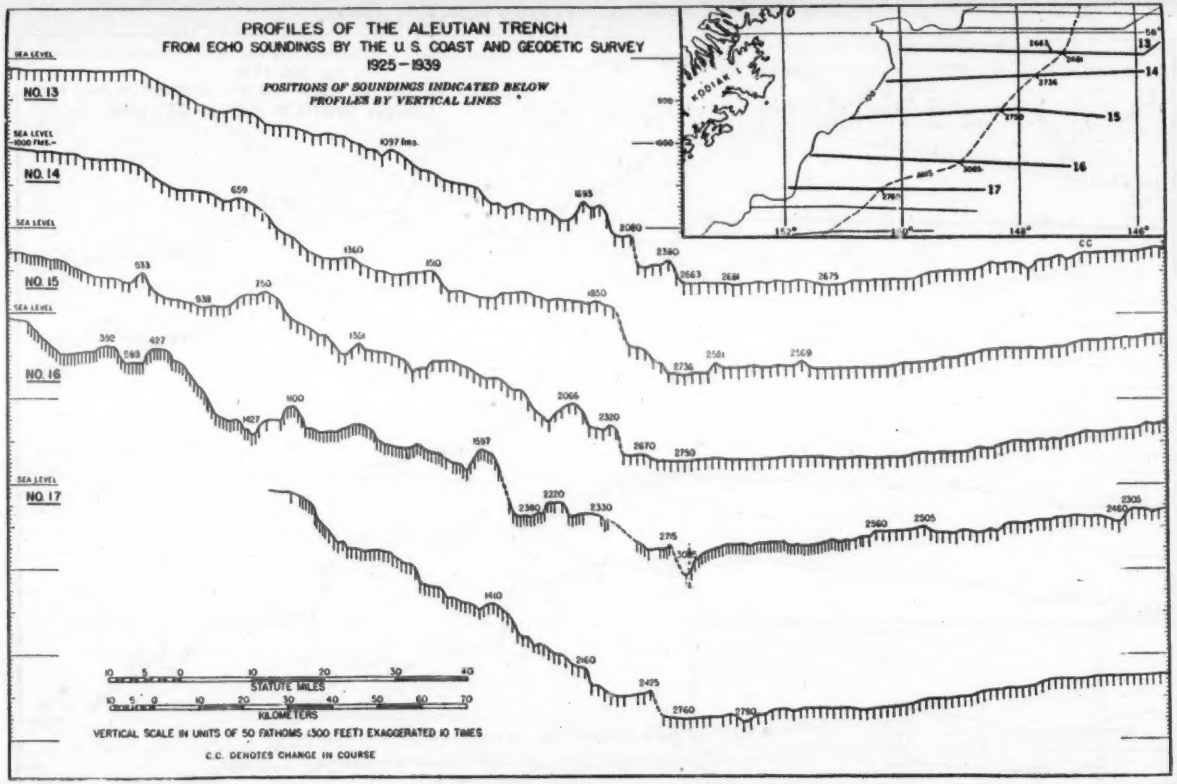

FIGURE 4.—*Profiles, Group III. East of Kodiak Island*

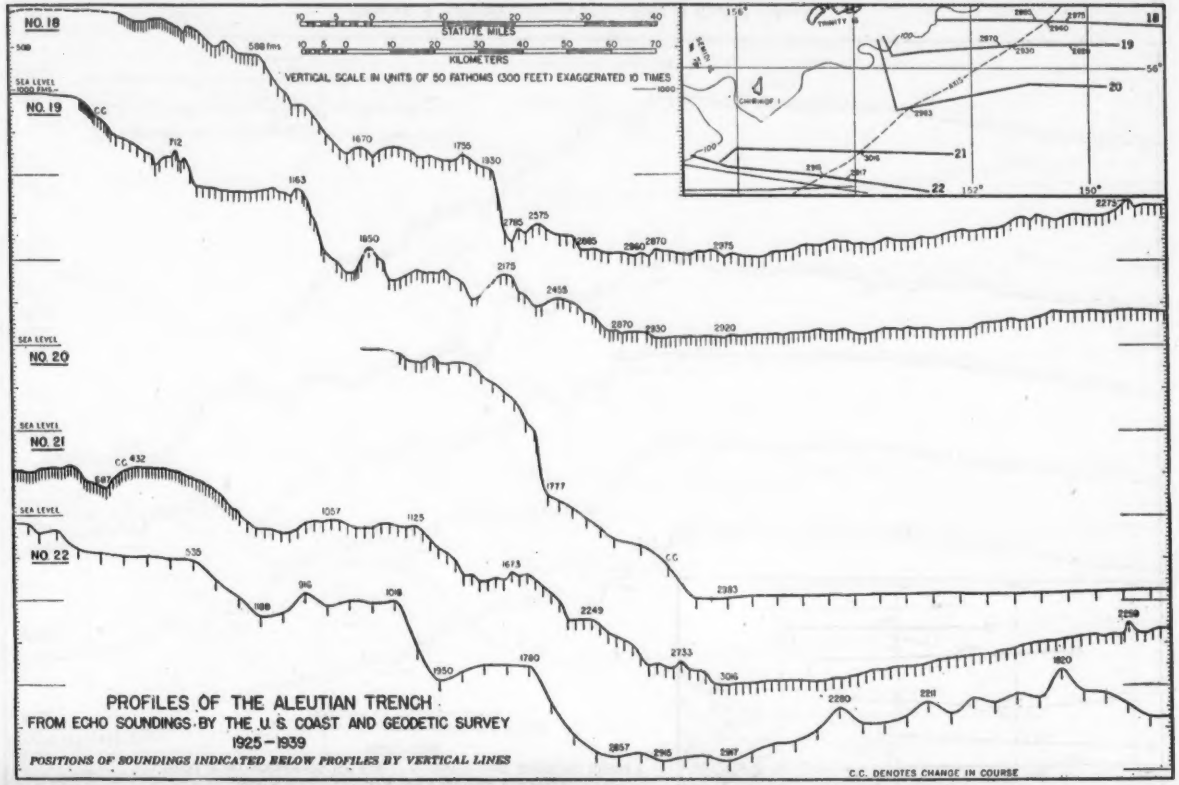

FIGURE 5.—*Profiles, Group IV. Off Chirikof and Trinity Islands*

FIGURE 5.—*Profiles, Group IV. Off Chirikof and Trinity Islands*

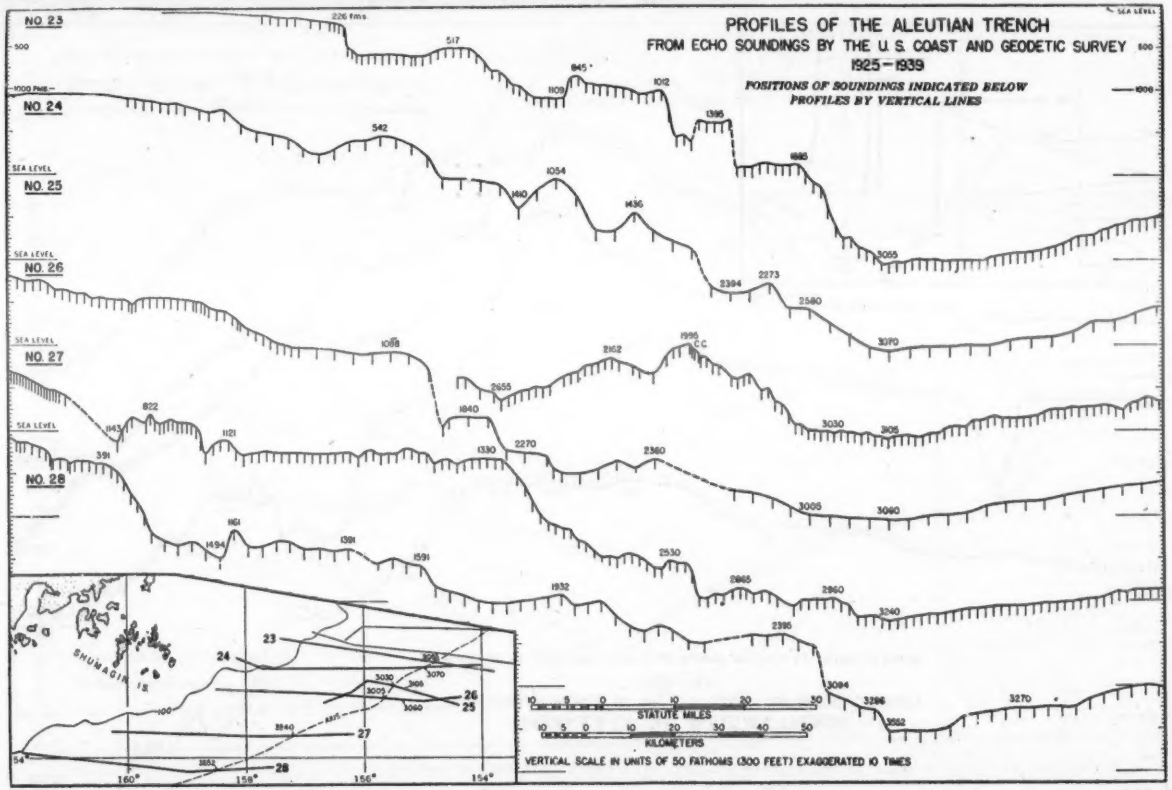

FIGURE 6.—*Profiles, Group V. Off Shumagin Islands*

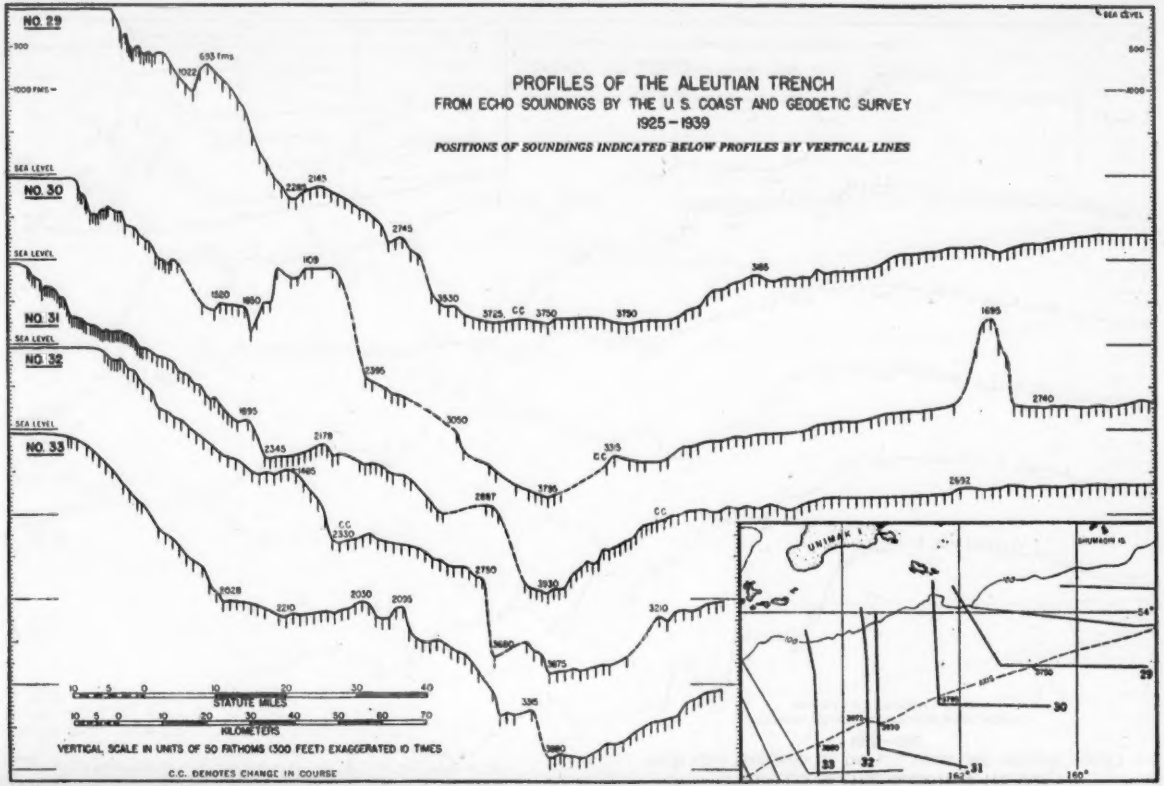

FIGURE 7.—*Profiles, Group VI. Off Unimak Island*

FIGURE 7.—*Profiles, Group VI. Off Unimak Island*

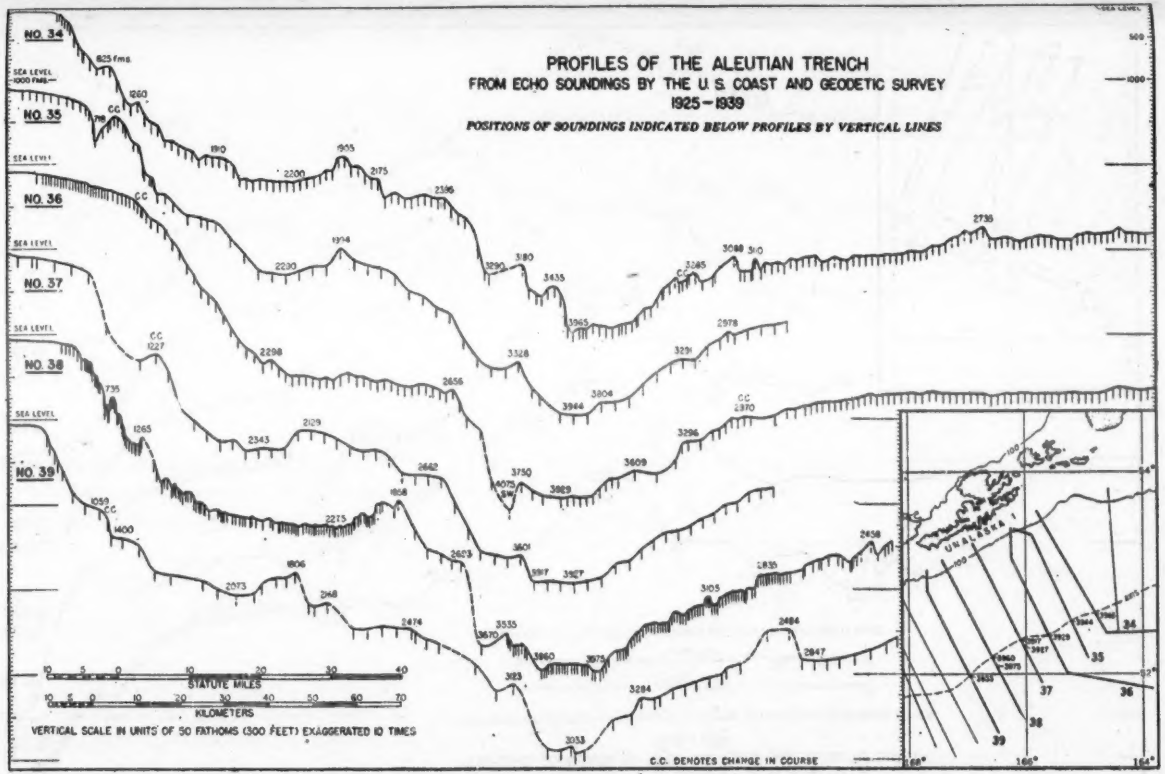

FIGURE 8.—*Profiles, Group VII. Off Unalaska Island*

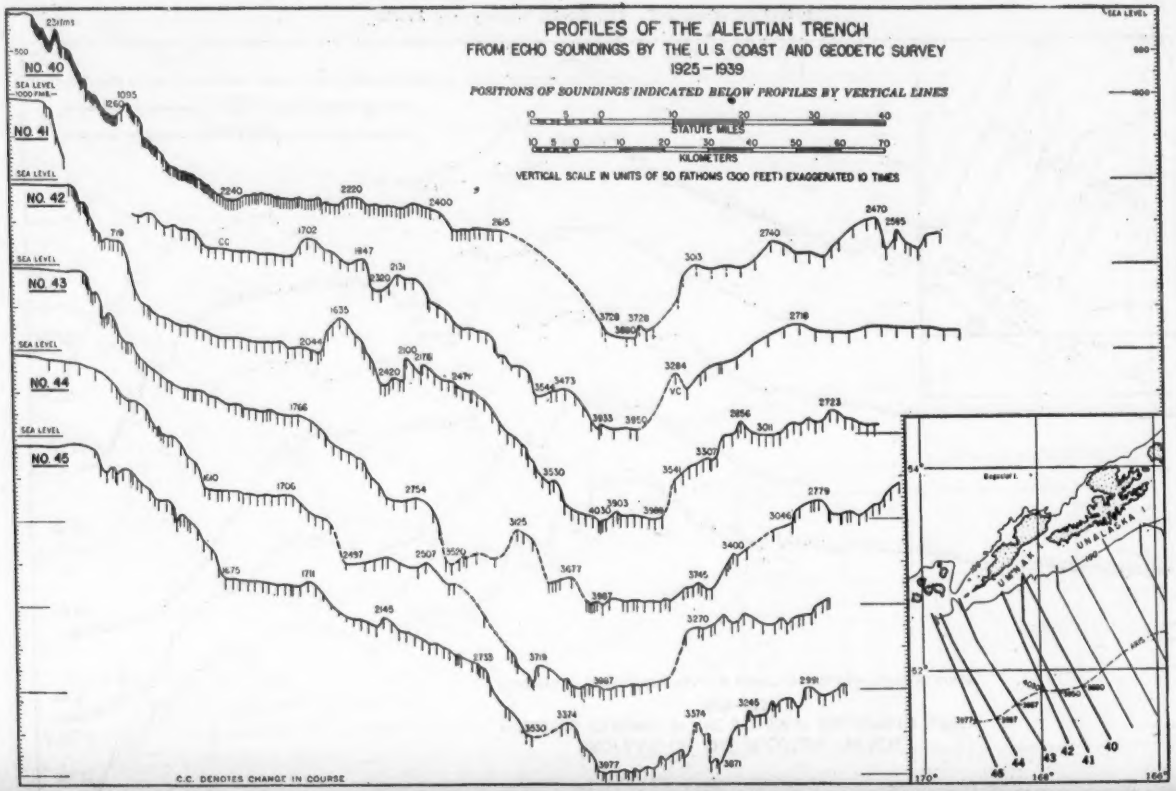

FIGURE 9.—*Profiles, Group VIII. Off Umnak Island*

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FIGURE 9.—*Profiles, Group VIII. Off Umnak Island*

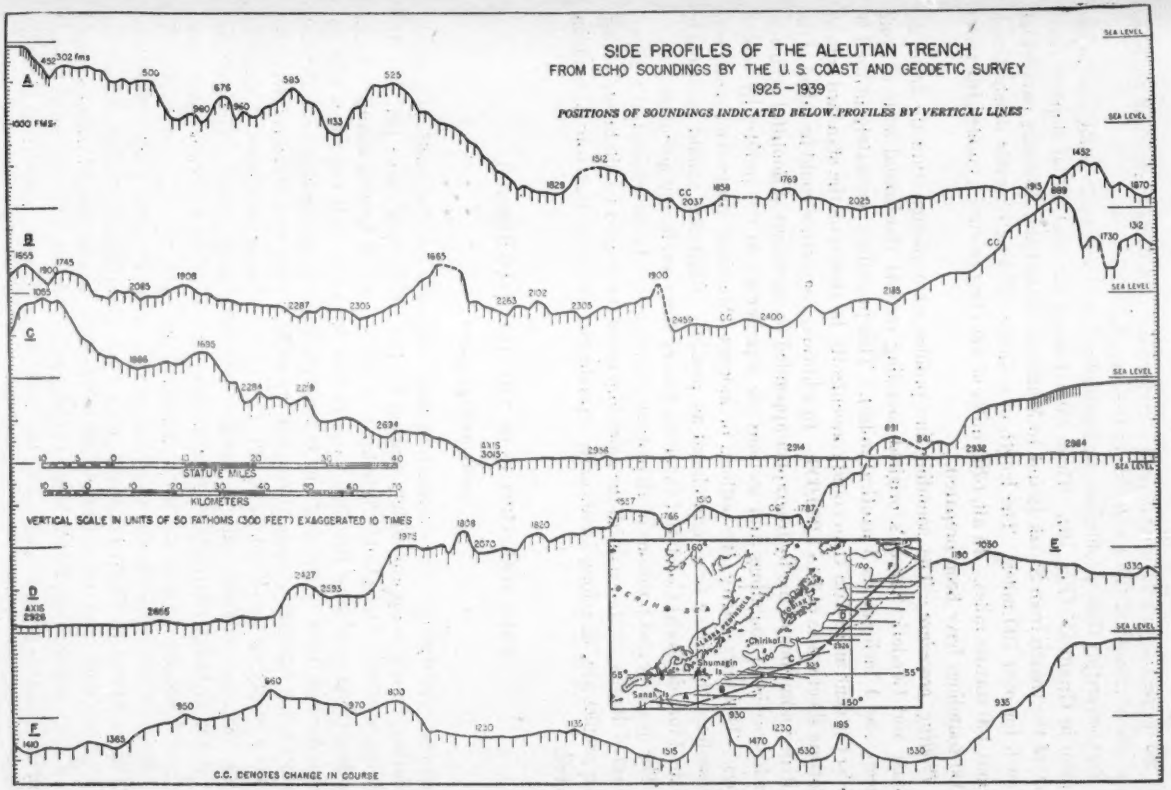


FIGURE 10.—*Profiles, Group IX. Along continental slope, Unimak to Middleton Islands*

on the deepest significant sounding in each profile. The deepest sounding is usually near the threshold of the north side of the trench.

Supplementing these profiles are six longitudinal or side echo-sounding line profiles shown in Group IX (Fig. 10). These extend along the continental slope or north side of the trench from Sanak Island to Middleton Island and generally parallel the trench for over 700 miles. The length of a single full-length profile illustration is about 140 statute miles. In all, 6200 miles of sounding profiles compiled from over 7000 soundings have been prepared.

Plotting procedure.—The sounding-line profiles were plotted directly from the Coast and Geodetic Survey's original sounding records (horizontal scale of work sheets was 1 inch equals 3 nautical miles). This procedure accurately utilized 20 to 50 per cent more data than could conveniently be shown on the standard smooth plotting sheet scales of 1 to 1,000,000. In addition, cognizance could be taken of the initialed notations of the hydrographer appended to soundings of doubtful accuracy. Such occasional soundings and sections are represented in the profiles by broken lines. To insure clarity, the outlines or indexes (Mercator projection) show only those lines that have been reproduced as profiles. Reference should be made to Plate 2 for additional Coast and Geodetic Survey lines run in any given area.

The quantity and positions of all plotted soundings can be ascertained at a glance. Selected depths are shown on all the more important features to facilitate referencing. The profiles are, therefore, an accurate reproduction of the hydrographers' sounding record.

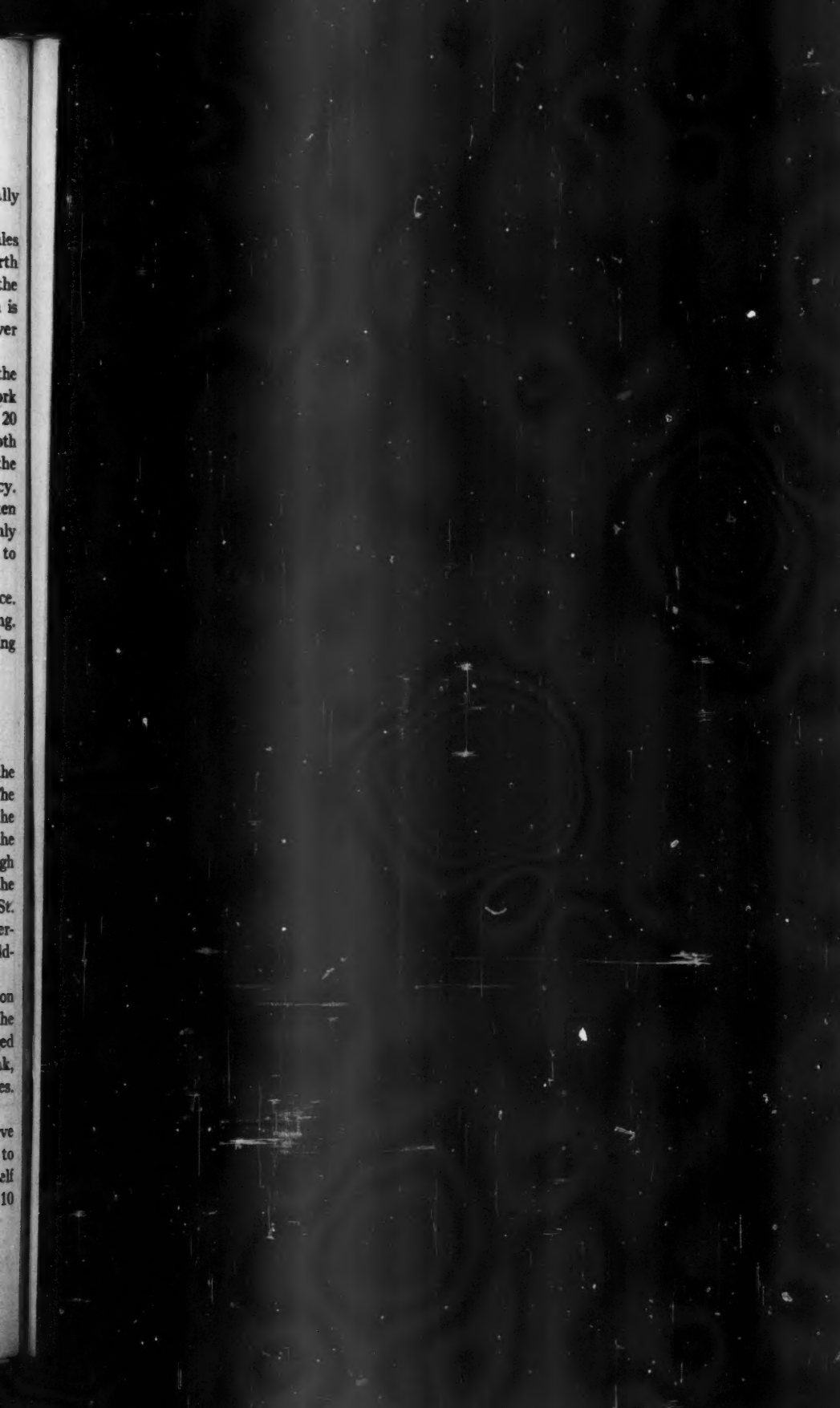
PRINCIPAL ASPECTS OF THE ALEUTIAN TRENCH

CONTINENTAL SHELF

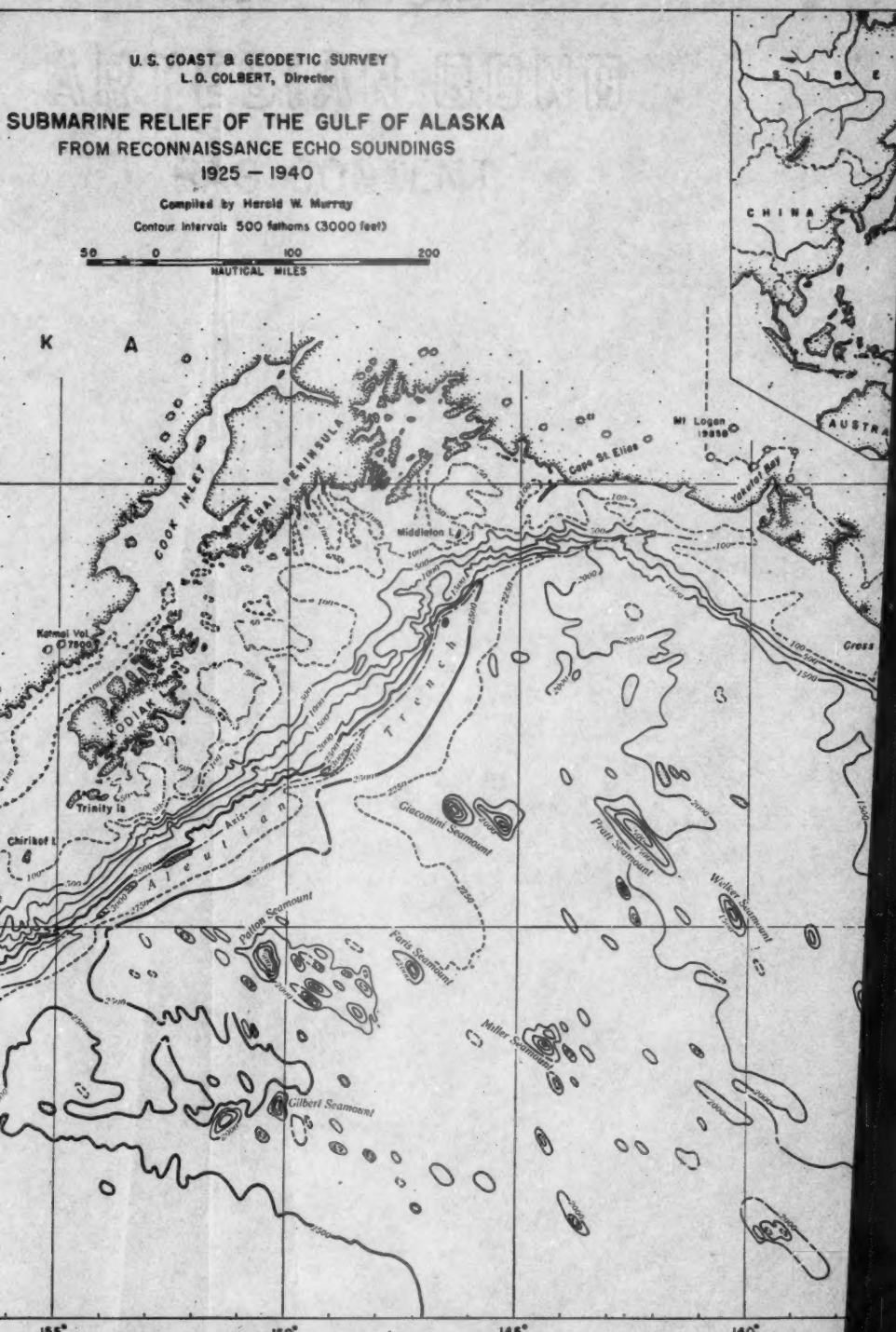
General description.—The continental shelf adjacent on the north side of the Aleutian Trench is approximately defined by the 100-fathom curve (Pl. 3). The maximum width of the shelf, 120 miles, is in the vicinity of Kodiak Island. To the northeast and southwest the shelf narrows to a few miles as it converges with the major land features. The coast line is generally irregular and precipitous, although there are interspersed occasional areas of low relief. Only two principal rivers, the Susitna emptying into Cook Inlet (Pl. 1) and the Copper northwest of Cape St. Elias, discharge sediment onto the shelf or into the inland waters. These glacier-fed rivers, although relatively short when compared with the Yukon or other world-famous rivers, are nevertheless heavy carriers of sediment.

Islands.—Numerous islands, large and small, emerge from the shelf. Middleton Island, southeast of Kenai Peninsula, with a low elevation of 126 feet, is near the edge of the shelf. In line with the Kenai Peninsula, Kodiak Island with its rugged shore line and elevation of 4462 feet is the largest and highest. Southwest of Kodiak, three small island groups trend across the shelf at approximate intervals of 110 miles. The Shumagin group attains an elevation of 2270 feet.

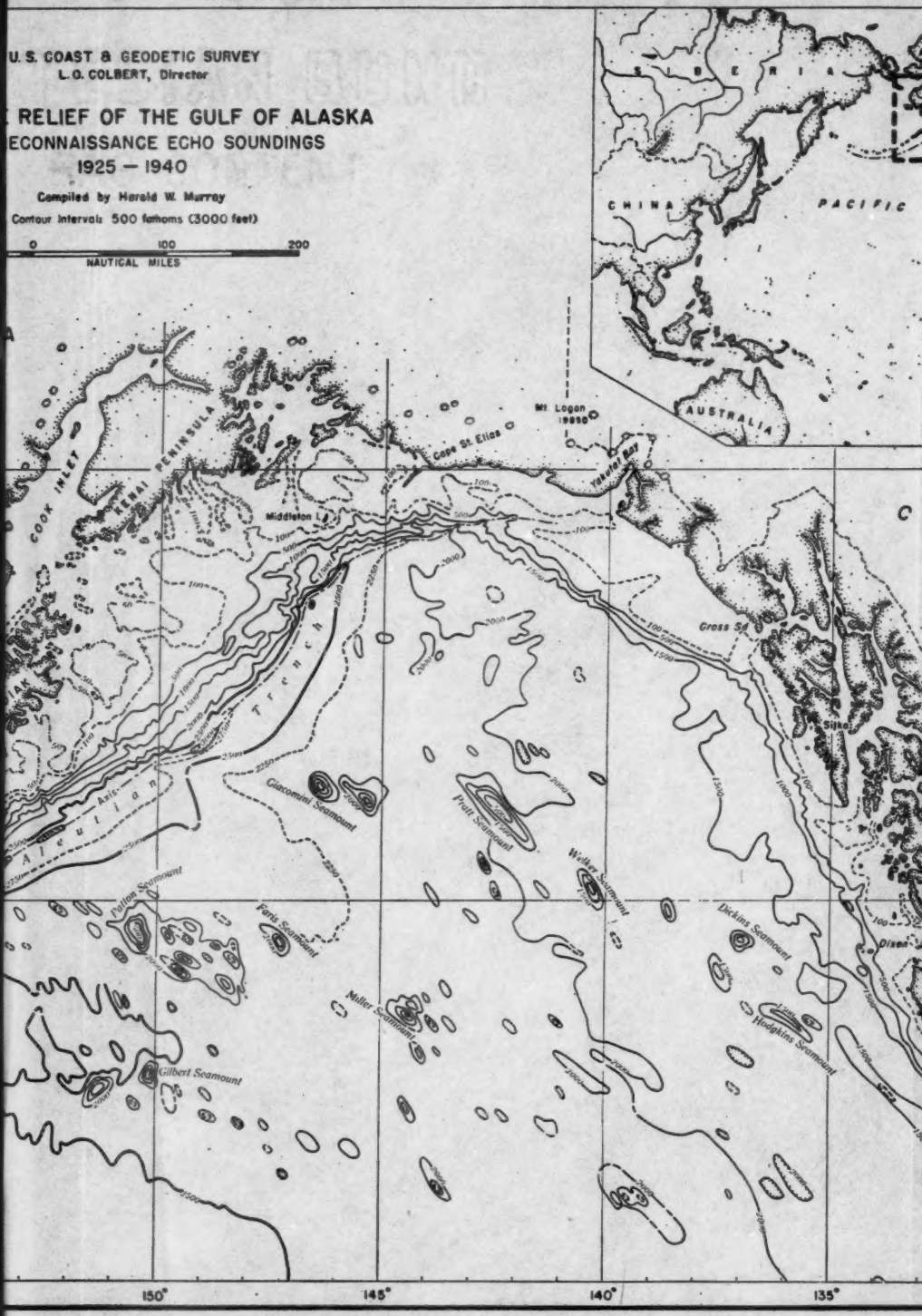
Banks and depressions.—Four submerged banks, delineated by the 50-fathom curve and with minimum depths of 8 to 25 fathoms, extend off Kodiak Island nearly to the edge of the shelf. Separating these banks and extending entirely across the shelf are broad depressions with an average width of 10 miles and varying from 60 to 110



170°
165°
160°
155°
60°
50°
YUKON RIVER
KUSKOKWIM R.
A L A S K
BERING SEA
ALASKA PENINSULA
Chirikof I.
Shumagin Is
Sanak Is
UNIMAK I.
Bogoslof I.
UNALASKA I.
AKUTAN I.
Is. of Four Mts
Axis



SUBMARINE RELIEF OF THE GULF OF ALASKA



UBMARINE RELIEF OF THE GULF OF ALASKA

ALASKA
UNITED STATES
OCEAN
SOUTH AMERICA
60°
C
A
N
A
D
A
55°
Dixon Entrance
QUEEN CHAR. IS
Hecate Strait
Queen Char. Sd
Dellwood Hills
VANCOUVER I.
50°
130°

fathoms deep. Other depressions radiate south of the Kenai Peninsula. Since these latter channels are continuous with the bays at the heads of which are live glaciers, they may have been formed by glacial scour. No glaciers exist at the present time on Kodiak Island. The south-trending channel just west of Middleton Island was attributed by Tarr and Martin (1914) to a glacial arm protruding from a former massive glacier in Prince William Sound on the north. This sound, having a maximum depth of 479 fathoms or about half a mile, is the deepest depression on the shelf. Enclosed continental-shelf depressions with depths exceeding 100 fathoms are not confined to the surveyed area eastward of Kodiak Island but are also revealed by reconnaissance surveys as far west as the Sanak Islands.

NORTH FACE OF THE TRENCH OR CONTINENTAL SLOPE

General description.—The continental slope comprising the inner north side of the foredeep is herein considered approximately as the area between the 100-fathom curve (50-fathom curve frequently applicable) and the floor of the trench. It ranges from 20 to 70 miles in width, is narrower near Cape St. Elias, and widest off Umnak and Unalaska islands. South of Unimak Island, a pronounced widening, herein termed the "Aleutian Bench", exists between the 2000- and 2500-fathom contours and extends westward to Umnak Island. This bench as sketched (*see also* figures 7, 8, 9, and 11) is approximately 20 miles wide and 170 miles long. The bench lies several hundred fathoms higher than the top of the outer seaward side of the trench.

The average slope of the north face or continental slope is 3°–4° and terminates in depths ranging from around 2000 to 4000 fathoms. Steeper slopes, however, are found in limited areas or between successive soundings. When the slope exceeds 30°, it usually occurs near the bottom of the trench where the profiles show an abrupt slope or escarpment as, for instance, the apparent escarpment off Cape St. Elias which is indicated in all six profiles in Figure 2.

The surveyed slopes on the north and south sides of the Umnak Island locality differ materially with respect to relief and rate of descent. The north side of the island is characterized by long valleys and ridges in the deeper area. For instance, the maximum seaward distance of the 1000-fathom curve on the north side of Umnak Island is 45 miles, whereas that on the south is barely 5 miles.

Submarine valleys.—A number of broad depressions or submarine valleys indent the continental slope. These are best developed in the vicinities of Umnak and Unalaska islands where the Coast and Geodetic Survey offshore surveys definitely reveal their descent to depths of 1500 to 2000 fathoms. The writer has recently contoured these surveys with a 25-fathom contour interval for use on the Bureau's navigational charts. Elsewhere, the valley indications are sketchy and must be evaluated accordingly.

FLOOR OF THE TRENCH

General description.—The floor of the trench, 20 to 70 miles off the edge of the continental shelf, undulates but steadily descends in the 1000-mile stretch from Cape St. Elias to Umnak Island. In many profiles, the converging side slopes of the trench

meet in a narrow area defined by one or two soundings at, or close to, the base of the continental slope.

A pronounced widening between the two 2500-fathom curves, and a flattening in the bottom and outer slope, occur on both sides of the bulge protruding northwestward from Giacomini Seamount. Off Unimak and Unalaska islands, a definite width of about 10 miles is indicated in the floor. The general depths in this latter vicinity range from 3900 to 4000 fathoms and approximate the maximum known depth of 4199 fathoms obtained near the westward end of the arc by the U. S. Coast Guard Cutter CHELAN in 1936.

The minimum depth of the trench below the top of the outer Pacific side ranges from about 200 fathoms, south of Cape St. Elias, to over 1600 fathoms, off Umnak Island. West of Umnak Island, no definite statement can be made. In the vicinity of Long. 175° West and 173° East, the depth appears to approximate 1600 fathoms (Fig. 13).

Eastern end of trench.—The gentle incline of the trench terminates at about 2000 fathoms, off Cape St. Elias. The trench, however, continues eastward across the continental slope and then apparently is continuous with a depression extending across the continental shelf toward Yakutat Bay. The delineation of the 100-fathom curve on the shelf here is inconclusive as it is controlled by only a few widely spaced soundings. A bar with depths of 8 to 16 fathoms extends entirely across the entrance to Yakutat Bay. Depths as great as 167 fathoms, however, are found about 4½ miles inside the Bay.

Contrasts in height.—The vertical relationship between the crest of the conspicuous mountain features and the floor of the trench is generalized in Figure 12. An approximate difference of 28,000 feet exists throughout most of the region. It is surprising, however, that, whereas the trench is over 2200 miles in length, about half this distance comprises the entire eastern incline, from Umnak Island toward Yakutat Bay; the other half approximates the deeper portion lying in depths of 3900 to 4199 fathoms. The approximate difference in the latter area between the trench and mountain peaks is about 30,000 feet. The greatest single known difference throughout the entire arc exists slightly east of the mid-section and is centered at Unimak Island (Pl. 1) where Shishaldin Volcano (9372 feet) rises 32,472 feet above the floor of the trench (about 110 miles distant) lying in depths of 3850 fathoms. When the depth of 3850 fathoms is added to the elevation of Mt. McKinley (20,300 feet), the highest mountain of the two Americas, only 130 miles north of Cook Inlet, the maximum contrast is 43,400 feet.

SOUTH FACE OF THE TRENCH OR OUTER SLOPE

Along the outer or south face of the trench gentler slopes and less irregularity in relief prevail. No submarine valleys are indicated. Off Umnak Island there is a departure from the general smooth configuration. The irregularity in the eastern portion of Profile 22 (Fig. 5) is at variance with the relative smoothness of the other profiles, and yet this is not surprising when it is realized that this locality is in line with the lesser seamounts trending across the gulf from the Patton Seamount group. Bulges in the outer slope resulting in a narrowing of the trench are prominent

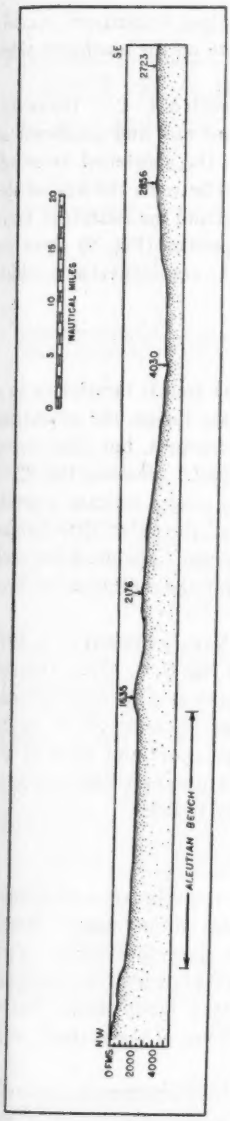


FIGURE 11.—*Natural scale section of Profile No. 42*

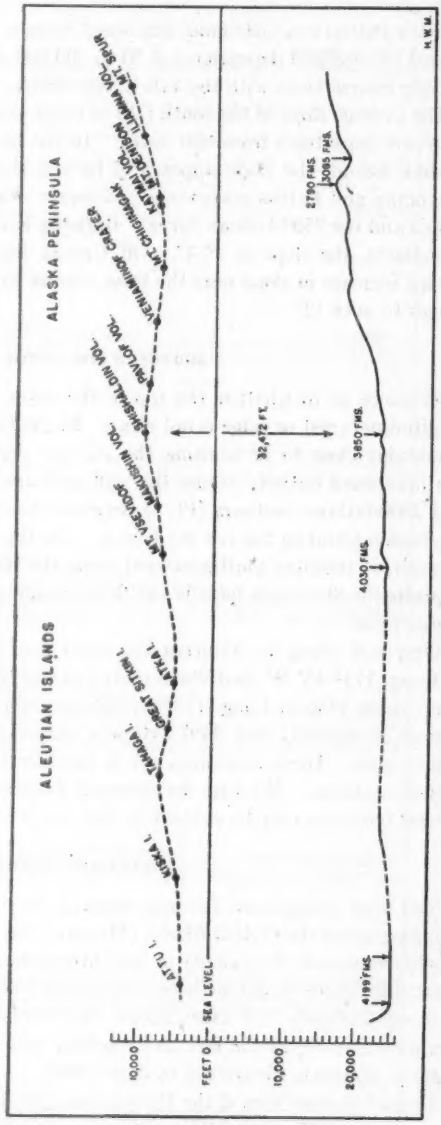


FIGURE 12.—*Generalized sketch of differences between floor of trench and prominent land features*

off both Patton and Giacomini Seamount ranges. These bulges, in turn, are accompanied by localized depressions of 50 to 300 fathoms in depth on the northeast sides of their intersections with the axis of the trench.

The average slope of the south face or outer side of the trench is 1°–2°. However, there are departures from this mean. In the broad portions east and southeast of Kodiak Island, the slope appears to be less than 1°. In the shortened areas off Giacomini and Patton seamounts, a 3-degree slope is found between the axis of the trench and the 2500-fathom curve. Between Kodiak Island and the Islands of Four Mountains, the slope is 2°–4°. Off Umnak Island, the profiles (Fig. 9) show an abrupt increase in slope near the base, similar to that on the continental side which ranges to over 12°.

SOUTHERN RIM OF THE TRENCH

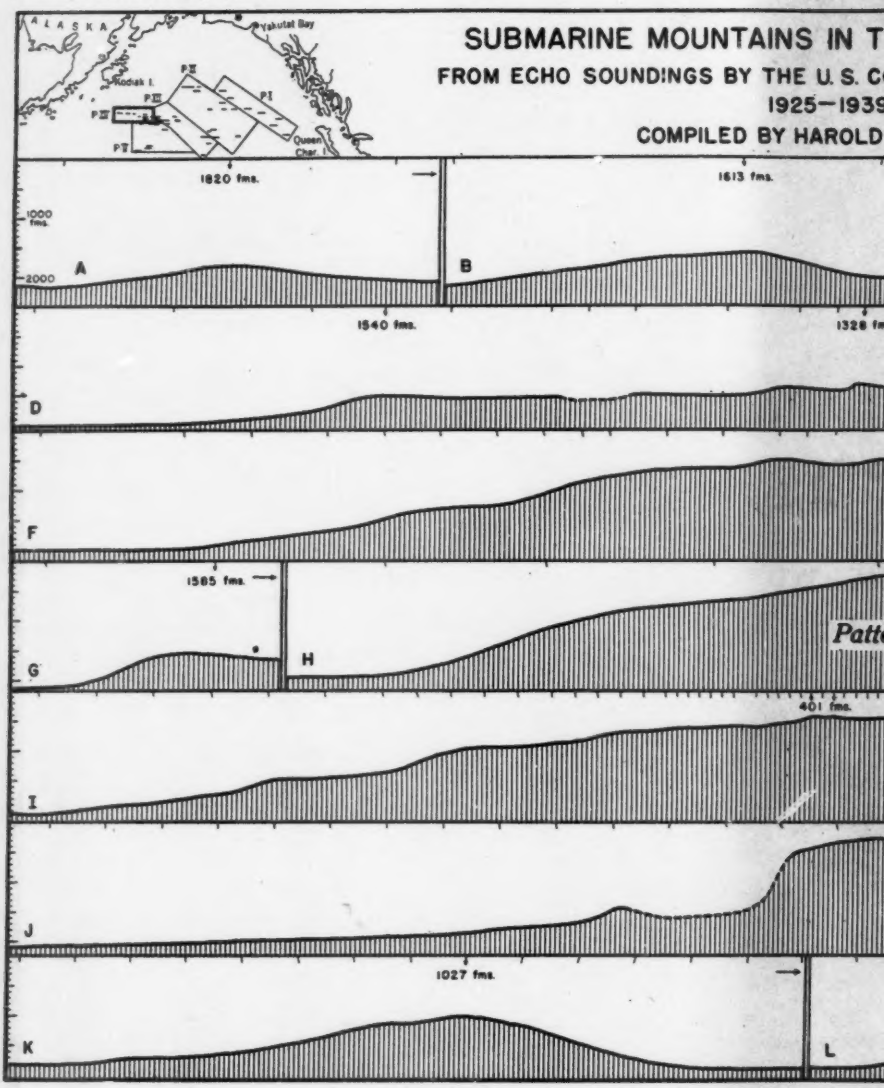
Evidence as to whether the top of the outer face of the trench terminates in a longitudinal crest or ridge is not clear. In the Gulf of Alaska region, the submarine mountains close to or fronting the rim are conspicuous features, but they trend southeastward entirely across the gulf and are not localized. Besides, the 2250- and 2500-fathom contours (Pl. 3) between these mountain ranges indicate a gentle depression trending toward the trench. On the other hand, the outer 2500-fathom contour, in trending southwestward along the trench from near Cape St. Elias until opposite the Shumagin Islands and then changing direction to the southeast, encloses higher relief.

Westward along the Aleutian Arc, one line of the U. S. Navy's BUSHNELL in 1934 in Long. 174° 45′ W. (not illustrated) and one (Fig. 13) of the U. S. Coast Guard's CHELAN in 1936 in Long. 173° E. indicate minimum depths of 2548 (approximate correction applied) and 2497 fathoms, respectively, about 50 miles south of the trench axis. These soundings are a considerable distance apart and warrant detached contours. If future development discloses more features of a similar nature, a crest tendency may be evident on the southern rim of the trench.

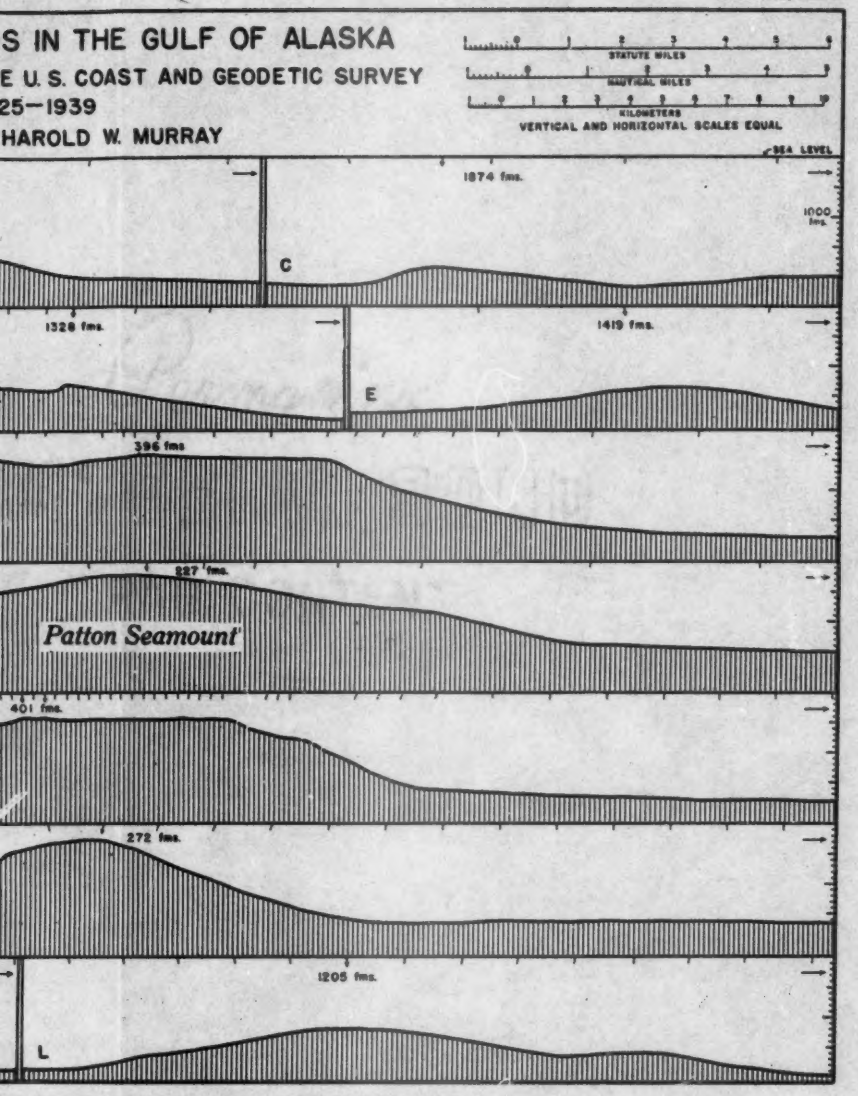
SUBMARINE MOUNTAINS

The most conspicuous features south of the trench are the submarine mountains trending across the Gulf of Alaska (Murray, 1941) to the edge of the trench. Sounding-line profiles in the vicinity of one of these mountains are shown in Plate 4. These mountains occur singly or in groups, appear to have truncated or irregular summits, and rise abruptly 1–2 miles above the surrounding smooth ocean floor. Patton Seamount, rising 12,438 feet and reaching within 227 fathoms of the surface, is the highest mountain discovered to date (1944).

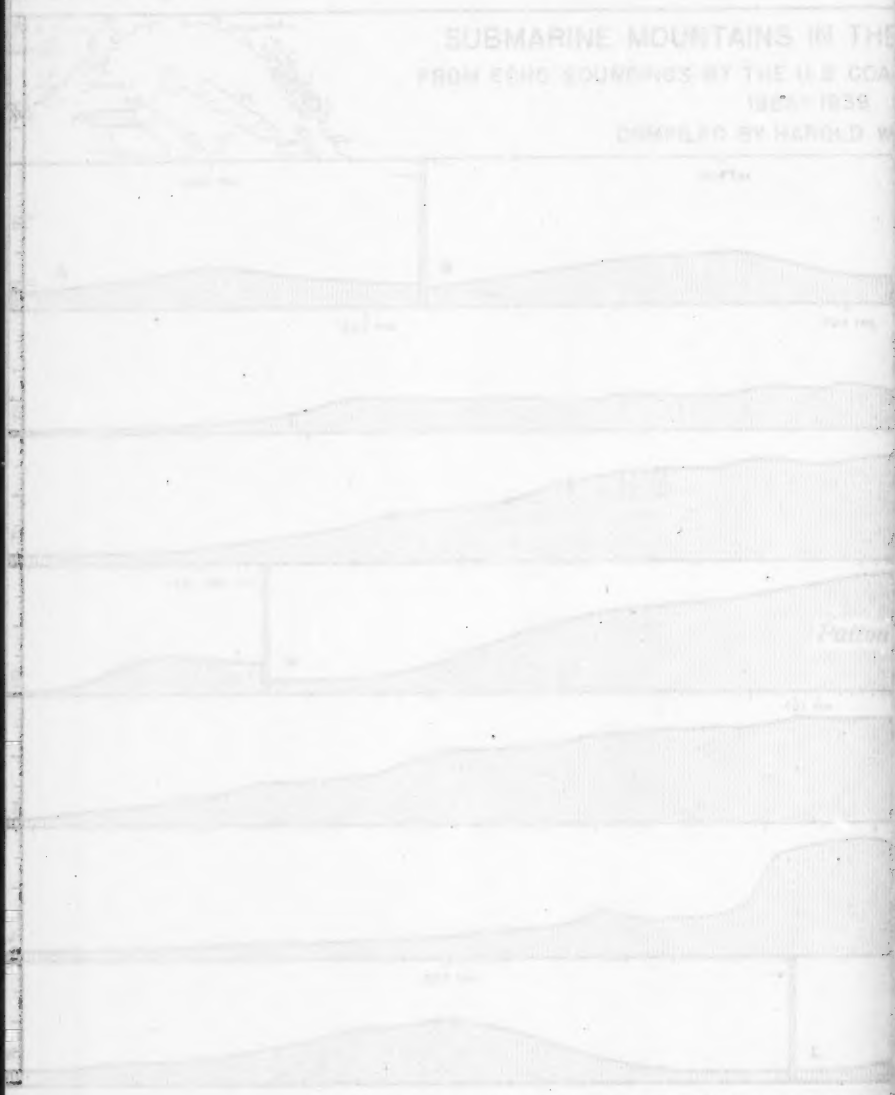
Five additional lines of the 1940 season necessitated a few alterations in the earlier contour map (Murray, 1941). Minor revisions were made just east of Patton Seamount. The Miller Seamount contours are now shown to be more oval in outline and separated from the small seamount 30 miles on the south. Miller Seamount, formerly indicated as about 6200 feet in height, is now known to rise over 10,000 feet above the bottom. A line passing across the southern end of Hodgkins Seamount confirmed the earlier delineation.



NATURAL-SCALE SOUNDING-LINE PROFILES IN TH



ES IN THE VICINITY OF PATTON SEAMOUNT



Additional low seamounts are shown southeast of Unimak Island. The northernmost seamount indicated in Profile 30, at 1695 fathoms (Fig. 7), rises 6270 feet above the surrounding bottom and is unusual in that it is on the outer face of the trench. The highest seamount in this vicinity, about 150 miles south of the Sanak Islands, lies in depths of about 1300 fathoms and rises 7900 feet above the bottom. It was discovered by the U. S. Navy Vessel SIRIUS in 1934. These seamounts are sketched from single lines, and the delineations have not been confirmed by other sounding data.

The six detached contoured features in the Gulf trending west by north from about 180 miles off Sitka, southeast Alaska, nearly to the edge of the trench may be associated with a pattern. This has not been stressed because of the minor magnitudes as at present revealed. The closed contours opposite the ends of this group enclose the higher features, the one on the east rising 200 fathoms above the bottom (1750-fathom broken-line contour) and the other on the west 374 fathoms (2000-fathom contour). The shallowest depths are 1615 and 1850 fathoms respectively.

Considering this region as a whole, the configuration presented is developed principally by east-west lines (Pl. 2) supplemented by two cross or check lines, which are the first of a series planned by this Bureau with a view to imparting rigidity of horizontal control and further developing this region in particular. At present, when contours are sketched and the same feature is apparently indicated on two adjacent lines, one is inclined to connect them, provided the distance between the lines is not too great. This adds length in one direction as in the case of Pratt Seamount. On the other hand, the more closely spaced lines in the vicinity of the Patton and Miller Seamount groups reveal that these latter mountains are apparently elliptical. Also, in trending northwestward across the Gulf, these mountains form a pattern abruptly transverse to the general southwestward trend of the trench and the mainland peninsulas.

BERING SEA

General description.—This sea is a relatively closed triangular-shaped basin bounded by two continents and the arc of the Aleutians. About half the area comprises the continental shelf, and the remainder lies principally in depths of 1600 to 2240 fathoms. The greater depths usually lie in the southwestern portion. The maximum depth cited, 2240 fathoms, lies 45 miles northeast of Attu Island (Fig. 13). The bottom at this depth is approximately 2 miles above the floor of the trench on the south side of the Aleutian Islands. Both broad divisions as outlined appear to be remarkably smooth except for an occasional island on the shelf and the extensive submarine mountain terminating in Bowers Bank.

Bowers Bank.—This bank is the crest of a singularly magnificent, arcuate mountain range conforming to a radius of approximately 125 miles (Fig. 14). It is about 60 nautical miles in width and 300 miles in length, measured as including Petrel Bank and Semisopochnoi Island which are continuous with the same bank. In rising from 2100 fathoms to within 74 fathoms of the surface, the bank attains a height of 2026 fathoms (12,156 feet).

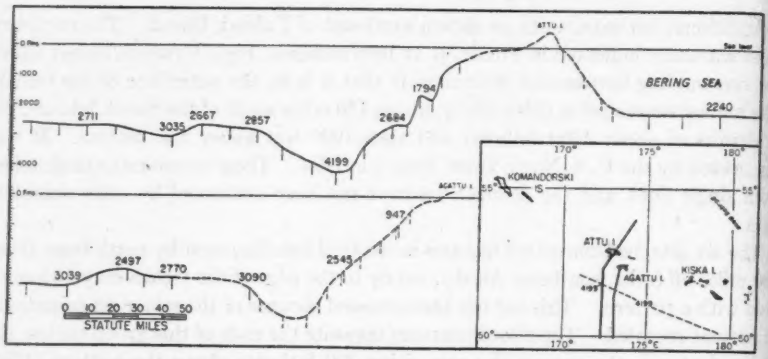


FIGURE 13.—*Profiles of the Aleutian Trench in vicinity of Attu and Agattu Islands, western end of Aleutian Islands*

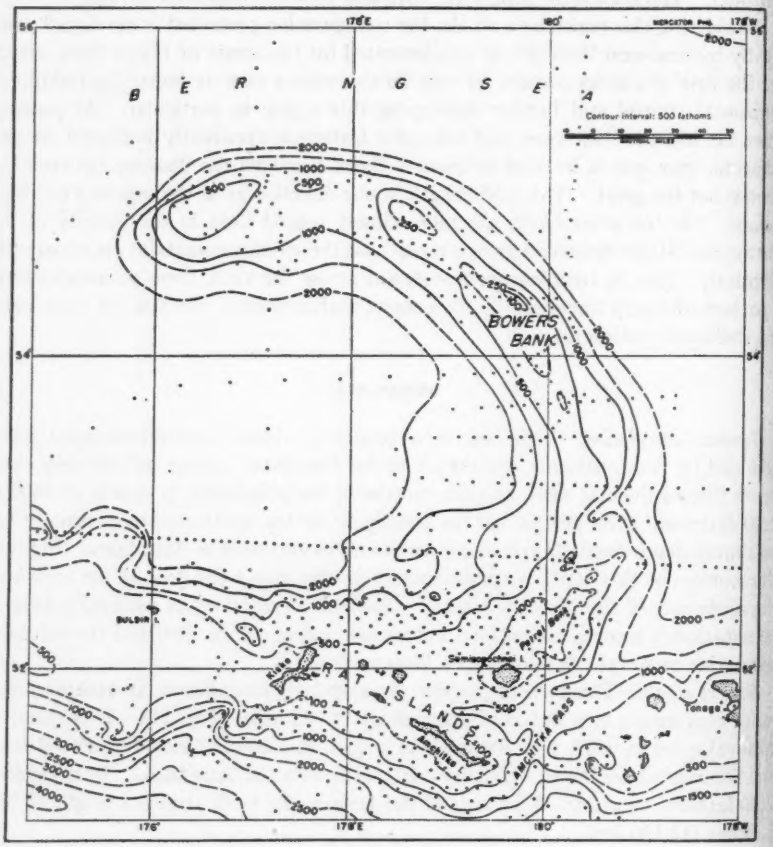


FIGURE 14.—*Bowers Bank and vicinity*

A depth of 310 fathoms was first obtained on the bank by the Fish Commission's ALBATROSS in June 1900. This vessel again visited the locality in June 1906 and obtained a depth of 74 fathoms at a near-by site. The extent of the bank, however, was not realized until 1936 when the U. S. Coast Guard's CHELAN made a complete reconnaissance.

The Bowers Bank range is unaccompanied by substantial depressions on either the convex or concave sides, but small features of the magnitude of 200 fathoms or more may exist between the present sparsely spaced soundings.

CONCLUSIONS

The Aleutian Trench is about 2200 statute miles long and 50 to 100 miles wide. It lies approximately 15,000 to 25,000 feet below the surface and 1200 to 9600 feet below the adjacent floor of the Pacific Ocean on the south. The maximum difference, 32,472 feet, between the crest of near-by land features on the north and the floor of the trench is near the middle of the arc. The western half of the trench lies south of the arcuate Aleutian Islands, the arc of the Aleutian Islands alone conforming to that of a circle for a distance of over 1400 miles. The eastern half of the trench consists of a steady incline to its terminus between Cape St. Elias and Yakutat Bay.

In the eastern Gulf of Alaska region, the inner north face of the trench or the continental slope is 20 to 70 miles wide and is quite irregular in relief. This side slopes at a rate of 3°–4° but may locally exceed 30°. The outer or south face slope is smoother in relief, and narrower. Conclusions regarding the general character of the deeper western half of the trench must await more data.

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